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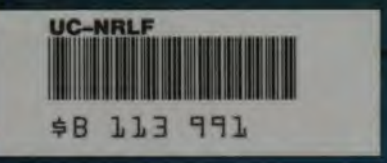

REPORT

OF THE

STATE BOARD OF HEALTH

ON THE

SEWERAGE OF THE MYSTIC AND CHARLES RIVER VALLEYS.

JANUARY, 1889.

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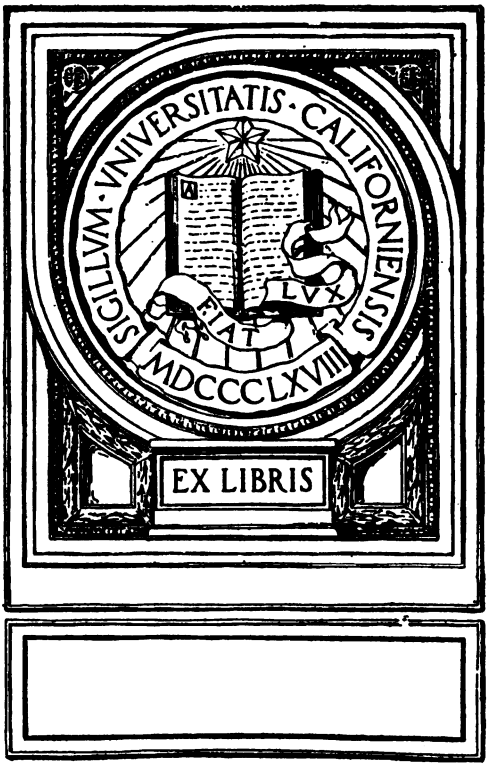
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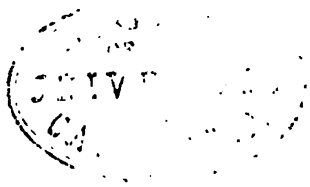


Commonwealth of Massachusetts.

REPORT OF THE STATE BOARD OF HEALTH

UPON THE

SEWERAGE OF THE MYSTIC AND CHARLES RIVER VALLEYS.

To the General Court of Massachusetts :—

THE Resolves of the General Court, under which the State Board of Health has made investigations relating to sewage disposal, and has made designs for a system of sewerage for the Mystic and Charles River valleys, are as follows :—

[Chap. 95.]

RESOLVE RELATING TO SEWAGE DISPOSAL IN THE MYSTIC AND CHARLES RIVER VALLEYS.

Resolved, That the state board of health is hereby authorized and directed to consider and report a general system of drainage and sewerage for the relief of the valley of Mystic river, and so much of the valley of Charles river, if any, whose relief in the opinion of said board is to be sought in conjunction with the Mystic valley system, and for such cities and towns, or parts of cities and towns as may, in the opinion of said board, be best relieved by the use of said system; and so much of the report of the commissioners appointed under resolve approved May twenty-eighth, in the year eighteen hundred and eighty-four, as relates to the cities and towns, or parts of cities and towns, which said board shall incorporate in the system to be reported under this resolve, is hereby referred to said board for its further consideration, and it shall be the duty of said board,—

First. To designate the cities and towns, and parts of cities and towns, which shall be tributary to and embraced in the district and system so to be reported, and to define the same by their report, with plans and maps.

Second. To define and show, by suitable plans and maps, such trunk line and main branches as it shall recommend to be constructed, with outlet.

Third. To define the methods by which said cities and towns, or parts of any city or town, may utilize said trunk line and main branches as an

outlet of a system of sewerage and drainage for said respective cities and towns, and said parts of cities and towns, and to show the same by plans and maps.

Fourth. To cause such surveys and levels to be made as will enable said board to determine with accuracy the location and grades of said trunk line and main branches, and also such surveys and levels in said cities and towns and parts of cities and towns as will enable said board to determine with accuracy the methods by which said cities and towns and parts of cities and towns may respectively utilize said trunk line and main branches and to report such methods by plans showing the main lines by which each may so provide for itself a system of sewerage and drainge with its outlet into said trunk line or main branches.

Fifth. To define the size and capacity of said trunk line and main branches and the materials of which they should be constructed and manner of construction, and such other particulars as will enable said board to determine the probable expense thereof.

Sixth. The expenses of surveys, maps and plans made to show the method by which any city or town, or part of city or town, may utilize said trunk line and main branches shall be separately kept, and the same, showing the amount expended in each, together with the expenses of the location and grade, maps and plans of said trunk line and main branches, together with all other expenses in the premises, and the items thereof, shall be reported to the governor and council, and all such costs and expenses shall be paid out of the treasury of the Commonwealth, on bills to be approved by the governor and council.

Seventh. Each city or town which wholly or in part said board shall consider should form a part of the territory to be embraced in the system to be reported shall be notified thereof by said board as soon as said board shall determine the cities and towns and parts of cities and towns which shall constitute said sewerage and drainage district. Said notice shall contain the names of the cities and towns wholly, and shall designate the portions of the cities and towns not wholly but in part, incorporated therein, and each of such cities and towns may confer with said board in respect to such drainage and sewerage system, and on request in writing be heard by said board on matters relating to the method of its utilizing said trunk line and main branches and the surveys, levels, maps and plans to determine and show the same, and under the superintendence of said board may, at its own expense, make its said surveys, levels, maps and plans for the use of said board; but all questions upon which any city or town shall desire to be heard shall be submitted to said board in writing with such request.

Eighth. Said board shall also consider whether any city or town within such district can more advantageously provide for itself a system of sewerage and drainage by itself and not as a part of said general system, and shall hear such city or town thereon if it shall so request, and shall also make report thereof.

Ninth. To ascertain and report the cost of the construction of said trunk line and main branches and outlet, and of the annual expense of operating the same, and also what cities and towns, or parts of cities and towns, would be obliged to pump their sewage or any part thereof, at

what places, the cost of the works therefor and the annual expenses thereof: *provided, however*, the whole amount expended under the provisions of this resolve shall not exceed the sum of ten thousand dollars; and reports under the same shall be made by the state board of health to the general court on or before the first Wednesday of January, in the year eighteen hundred and eighty-nine. [*Approved June 16, 1887.*

[Chap. 42.]

RESOLVE IN ADDITION TO A RESOLVE RELATING TO SEWAGE DISPOSAL IN THE MYSTIC AND CHARLES RIVER VALLEYS.

Resolved, That there be allowed and paid out of the treasury of the Commonwealth, a sum not exceeding fifteen thousand dollars, to be expended under the direction of the state board of health in continuing the investigations relating to sewage disposal in the Mystic and Charles river valleys as authorized by chapter ninety-five of the resolves of the year eighteen hundred and eighty-seven; said amount being in addition to the ten thousand dollars provided for in said resolve. [*Approved March 22, 1888.*

[Chap. 63.]

RESOLVE PROVIDING FOR FURTHER INVESTIGATIONS RELATIVE TO SEWAGE DISPOSAL IN THE MYSTIC AND CHARLES RIVER VALLEYS.

Resolved, That the state board of health be requested to designate some method for the disposal of the sewage of such cities and towns as are embraced within the lower valley of the Charles river, in the report of the commissioners appointed under chapter sixty-three of the resolves of the year eighteen hundred and eighty-four, as they may not include in their report under chapter ninety-five of the resolves of the year eighteen hundred and eighty-seven, and so much of said report as relates thereto is hereby referred to said board for its further consideration. Such designation shall be made as a part of the report required by chapter ninety-five of the resolves of the year eighteen hundred and eighty-seven, and the expense thereof charged to the appropriation provided for in chapter forty-two of the resolves of the year eighteen hundred and eighty-eight. [*Approved April 24, 1888.*

The territory whose relief is, under these resolves, to be considered by the State Board of Health, includes an area of one hundred and thirty square miles, and contains one-sixth of the population of the State.

Some of the cities have more or less complete local systems of sewerage, discharging sewage at their borders, where it is offensive to their own citizens and to their neighbors, and has become, or is rapidly becoming, dangerous to the public health. Others of the cities and the more populous towns have little or no sewerage systems, and are waiting, with solicitude for the health of their people, the action of the General Court in arranging for a common method of disposal of their sewage, being prohibited by statute,

or by considerations of public health, from pouring it into the streams which are the natural drains of their territory; and still other towns, sparsely settled, see less need for disposal of their own sewage, but are much concerned for the health of their communities, because of the pollution of streams upon their borders by the sewage of their neighbors.

To devise the most efficient systems of relief for these communities, and to present plans which, upon careful consideration, would meet their approval as the best that can be adopted, required that the problem should be solved in all of the three practicable methods of solution that have met with favor elsewhere.

These methods are: —

1st. The method of discharging crude sewage into a strong tidal current that will convey it to sea, whence it cannot return.

2d. The method of partial purification by filtration upon the bed recommended by the Massachusetts Drainage Commission by report of Dec. 24, 1885, or upon some other bed or beds.

3d. By chemical precipitation and discharge of the clarified effluent into outgoing tide at one or more points.

The Board concluded that the general consideration of each of these methods should be committed to a thoroughly competent engineer, skilled in the particular method to be planned by him, and that he should take time to investigate the whole subject in its relation to this locality, and work up the best plan for his method of disposal.

The Board selected Mr. Howard A. Carson, civil engineer of Boston, who had been the superintendent of construction of sewers of the Boston Main Drainage System, and went abroad with Mr. Davis to study the discharge of sewers into tidal currents, to make the investigations, plans and estimates by the first method, which plans and estimates for sewers, modified to meet the peculiar conditions, are used in the estimates of cost by the other methods; Mr. Phinehas Ball, civil engineer of Worcester, to make the investigations, plans and estimates appropriate to the second method; and Mr. Charles H. Swan, civil engineer of Boston, to make the investigations, plans and methods appropriate to the third method.

After careful examination of the possible localities for disposal of the sewage, Mr. Carson concluded that the best outlet for the discharge of crude sewage is a little west from the Beacon which is one-third of a mile south from Deer Island. Mr. Ball found that territory including and in the vicinity of that selected by the Massachusetts Drainage Commission of 1885 is the only available territory where any considerable portion of the sewage of Mystic

valley can be treated by filtration; and Mr. Swan selected as the most favorable for the chemical precipitation process an area in Everett, on the north bank of Mystic River, between Malden Bridge and Island End River.

A system of intercepting sewers was first designed and located upon the ground, and estimates of cost made, for receiving and conveying to each of these points of disposal the sewage from Woburn, Stoneham, Winchester, Arlington, Belmont, Medford, Melrose, Malden, Everett, Chelsea and East Boston, and one-fifth of Somerville and one-ninth of Cambridge, containing a population estimated to be 150,000 in 1890 and to increase to 300,000 in 1930, the sewers being of sufficient capacity to serve the population of 1930.

With the estimated cost of these systems of sewers by Mr. Carson, and the estimates of Mr. Swan for the process of disposal by the aid of chemical precipitation, the chief engineer and the consulting engineer of the Board made for the use of the Board a comparative estimate of the cost and yearly running expenses for each of the three methods of disposal, which comparative estimate is here given to indicate the steps by which the Board has reached its final conclusions.

Comparative Estimate of Cost of Sewers for Mystic Valley for a Prospective Population of 300,000, used at first by a Population of 150,000.

	If crude sewage be discharged continuously into tide water at Deer Island Beacon.	If sewage be filtered on Saugus Marshes.	If sewage be precipitated by chemicals at Island End River, and effluent be discharged at ebb tide.
First cost,	$2,726,995	$2,654,626	$2,384,503
Yearly running expenses and maintenance,	$55,760	$66,700	$132,800
Interest and sinking fund at 4¾ per cent.,	129,532	126,095	113,264
Total yearly cost,	$185,292	$192,795	$246,064
The same sewers used by a population of 300,000			
First cost,	$2,792,995	Filtering area insufficient for so large a population.	$2,835,651
Yearly running expenses and maintenance,	$72,020		$222,300
Interest and sinking fund at 4¾ per cent.,	132,667		134,693
Total yearly cost,	$204,687		$356,993

These estimates show that the amount to be paid on the cost and maintenance of works, and yearly running expenses for the forty years for which the systems were designed to be adequate for the territory embraced, is more than 50 per cent. greater for the method of disposal by chemical precipitation at Island End River and discharge of the clarified sewage there on the out-going tide, than for the method of discharge of crude sewage into tidal currents at Deer Island Beacon.

When we consider a larger population than the 300,000, and find that the cost of chemicals and their application and the removal of sludge will be as much as fifty cents per inhabitant a year, while the whole yearly running expenses by the method of discharge at Deer Island are but one-half this amount, we must conclude that if a larger territory as favorably situated in respect to the outlet at Deer Island be included in a system discharging there, the resulting cost will to a much greater degree be in favor of the Deer Island outlet.

This result, though not anticipated by the Board, was received with satisfaction, because the effluent from chemical precipitation in England has been found to contain nearly one-half of the putrescible material of the sewage, and in some cases it has been found necessary to still further purify it by filtering it through land before turning it into streams. In this case it is to be turned into a large body of salt water, upon which it will tend to float, and, on the first ebb, will be carried down to Fort Point channel, and with the returning tide backed into the Mystic, Chelsea and Charles rivers: in the first river, nearly to the starting point, and in the last, about up to Craigie's Bridge. On the second ebb, the new discharge of clarified sewage will mingle to some extent with water containing the former discharge, so that, as Mr. Swan shows, there will always be the effluent from as much as one and one-half days' sewage in the waters about the principal wharf fronts of Charlestown, Chelsea, East Boston, East Cambridge and Boston.

This effluent is expected to be nearly colorless and clear when discharged, and will probably not be recognized as sewage after being in the river an hour. It will probably be mingled, to some extent, with the water of the river and harbor throughout its depth, but, being lighter than the salt water, will, during its passage back and forth past the wharves of these cities, probably be mingled to the greater extent with the water at and near the surface. In calm, moist weather we can but anticipate a marked effect of this surface water containing putrescible matter in adding to the discomfort of the great number of people who breathe the muggy air which has slowly moved over these waters.

Intercepting the sewage that now enters these waters, collecting it, — together with large additions from the surrounding country, — treating it with chemicals which remove the objectionable appearance and present odor of sewage, but still leaving in it one half, more or less, of the constituents which chemically distinguish sewage from pure water, and pouring this back, in ever-increasing quantity, into these rivers, surrounded by so dense a population, is a scheme to which the State Board of Health would be unwilling to give its approval, until satisfied by experiments which have not yet been made that the result would not be detrimental to the public health. Moreover, finding the cost of removing the sewage beyond all habitations and turning it into the ocean to be decidedly less than the cost of the questionable method by chemical precipitation, the Board is relieved from further investigation of the latter method, and dismisses it as inapplicable to the present circumstances.

The ordinary quantity of sewage to be pumped daily we have concluded to regard as 110 gallons per inhabitant, when serving a population of 150,000, and 120 gallons per inhabitant when this population grows to be 300,000, — making 16,500,000 gallons per day to be pumped presently after the completion of the works, and 36,000,000 gallons to be disposed of forty years later.

The area required to filter these quantities of sewage varies within a very wide range, depending upon the character and the porosity of the filtering material and the disposal to be made of the effluent.

The Board has made very extended experiments upon the Saugus Marshes to determine the quantity of water that will go down through the surface when kept constantly covered with one or two inches of water, and underdrained at the depth of six feet, and the water in the drains kept from three and a half to five feet below the surface.

Experiments have also been made to learn the quantity that would pass through where the surface was kept covered but a part of the time.

These experiments were in charge of Mr. Ball from their commencement in April till the latter part of July, when owing to ill health he found it necessary to discontinue work, and they were continued till the 1st of October in charge of Mr. Fred. Brooks, civil engineer of Boston, whose report is appended.

At each of four different places on these marshes two circular beds were arranged with underdrains, and dikes to prevent overflow by the tide. One of these beds retained the surface of turf;

the other had the turf to the thickness of four inches removed and the surface spaded up as if to be planted.

Upon these beds, about fifteen feet in diameter and separated from the surrounding marsh by a low embankment, water was applied to the depth of two inches. Outside of this embankment, a few feet away, was a second encircling embankment; and outside of this, a third embankment. Between these embankments water was kept, as near as practicable, at the same height as in the interior area.

At one place, intermediate between two others, a single bed ten feet by twenty feet was built, with the three lines of encircling embankments; in this bed the surface of turf was retained.

Arranging the beds in the order of the depth of peat, we give in the following table the quantity of water that passed through the surface of each when kept continually covered with water, while the water in the underdrains was kept from three and a half to five feet below the surface: —

Depth of Peat.	Quantity of Water passing through the Surface when continually covered.	
	In Gallons per Acre per Day.	
Feet.	Natural Surface with Turf.	Turf removed and Surface spaded.
1.5	39,000	34,000
1.7	40,000	–
2.1	100,000	32,000
3.5	21,000	23,000
5.0	3,500	3,800

Experiments were made at six of the beds on the marsh to see the effect of allowing the surface to remain dry, after each application of water, as long a time as it took for about two inches in depth of water to disappear. The result of this intermittent treatment, with intervals of one to two days, continued for ten days or two weeks, was, that very little increase of capacity to transmit water followed such intermission; so that during a month when the surface is covered with water half the time, but little more than half the quantity of water will flow through that will flow through if it be kept constantly covered.

The experiments of the Board upon the filtration of sewage by other material than peat show that the amount of sewage that can be filtered, month after month, is very much less than the amount of clear water that will continually flow through the material of the filter.

Most of the good filtering materials with which the Board has experimented will allow from ten times to one thousand times as much clear water to flow through them as the marsh surface, and will filter, giving an effluent suitable to turn into Pines River near a bathing beach, from less than one per cent. to more than six per cent. of the amount of clear water that will at first flow through them. But the material, not peat, which has filtered satisfactorily, and which is most nearly comparable with the marsh material, is composed of fine and coarse sand and a little fine gravel, overlaid by about twenty inches in depth of yellow loam and brown soil. This material allowed three times as much clear water to pass through it as the average of the marsh, and for a time filtered satisfactorily for the purpose there required one-third as much sewage as it at first passed of clear water; but this quantity of sewage grew less by the choking of the surface, until but one-twentieth as much would pass as originally of clear water. Then the surface was scraped off to the depth of half an inch, when it filtered readily and satisfactorily a quantity of sewage equal to one quarter of the original quantity of clear water; but this quantity gradually grew less and in one month filtered but one-eighth of the original quantity of clear water.

These results induced the Board to make experiments to determine, as near as practicable in the time at its disposal, the amount of sewage that can be filtered by material taken from the marsh at the location of the four double beds above described. When digging the drain between the two beds at each place a pillar of the material two feet square and five feet high was left; and this was carefully cut in layers six inches deep and placed in order in boxes, which were taken to the experimental station at Lawrence; and each layer was carefully cut to a circle twenty inches in diameter, and the bottom layer was placed in a galvanized iron tank twenty inches in diameter, upon a bed of six inches of coarse and fine gravel and coarse sand, which served as an underdrain; and each layer from the marsh was placed above this, in its order, filling the tank to the depth of five feet. Four tanks, filled in this way, represented as nearly as practicable the actual condition of the material in the marsh at the four localities.

Sewage has been applied to the peat in these tanks in such quantities as it would receive, for six and seven months, with

results which are given in much detail because of their importance in deciding the question of the practicability of filtering sewage through a layer of peat.

Tank No. 1 of material from Saugus Marsh, having one and a half feet in depth of peat, with the peaty sand and clear sand below, making a total depth of five feet, being completely underdrained, was supplied with sewage, keeping the surface covered continually with a depth of about five inches, for three months, with the following result: —

During the first month the flow from bottom of tank was at the rate of	22,000	gals.	per	acre	per	day.
During the second month, at the rate of	16,000	"	"	"	"	"
During the third month, at the rate of	9,200	"	"	"	"	"

During the fourth month the sewage on the surface, five inches deep, was allowed to settle away and disappear, which it did in twenty-eight days. The quantity flowing out decreased to 5,000 gallons on the fifth day, and on the day before sewage disappeared from the surface the quantity flowing was but 2,400 gallons per acre. For the next three weeks about the quantity which came out was applied intermittently, allowing the surface to become uncovered after each application, and the quantity flowing out decreased to 1,200 gallons per acre per day. At the end of this time the surface dried sufficiently for the mass of peat to shrink away from the sides of the tank, leaving a crack through which liquid could flow down freely for some distance, so that the quantity increased for a week to 11,000 gallons per acre per day; but by keeping the surface continually covered, the peat again swelled and the crack filled with slime, and the average daily outflow for the sixth month was 5,200 gallons, decreasing in the latter part of the month to 3,600 gallons, and during the seventh month the average daily flow for three weeks was 3,000 gallons, decreasing to 2,400 gallons per acre per day.

It is evident that the sewage came through this material, for the chlorine from the salt marsh decreased in the first two months from 1,200 parts in 100,000 to 75 parts, and has since decreased to 31 parts. The ammonias, being in the first sample 0.10 parts in 100,000, decreased nearly in proportion to the decrease in flow in two months to 0.02 parts, and have since increased and averaged during the past month 0.26 parts.

The effluent is now suitable to turn into an arm of the sea near a bathing beach, but as no nitrification takes place it is probable that the filtering material is storing up ammonia that will come out later, rendering the effluent objectionable. Keeping the

surface continually covered with sewage, as in the earlier experiments, the surface becomes covered with a disagreeable slime, which, on account of the very slow percolation of the liquid, accumulates rapidly, and, no doubt, has the effect to close up the interstices of the peat and cause the amount flowing through to decrease so rapidly. But the choking of the surface appears in the later experiments to be more complete when the water is allowed to drain out of the slime after it has been deposited.

Saugus Marsh tank No. 3, which had a depth of two and a half feet of peat overlying peaty sand and sand, was treated with sewage at the rate of 30,000 gallons per acre per day for three months, which flowed through with the slight decrease attributable to evaporation. This quantity did not keep the surface continuously covered. The quantity was increased to 60,000 gallons, which disappeared for three days and then began to accumulate upon the surface, and in the next two weeks an average flow of 45,000 gallons ensued; but the quantity flowing was growing less, and 30,000 gallons applied accumulated upon the surface. Then for two weeks 20,000 gallons, applied daily, accumulated, and all application of sewage was stopped until that upon the surface should disappear, which occurred in seven days, in which time the average flow was at the rate of 15,600 gallons per acre per day. During the next week the rate of 11,400 gallons per acre did not keep the surface continually covered; but a daily application for the next four weeks of 12,860 gallons per acre kept the surface continually covered, and the effluent was at the rate of 12,000 gallons per acre per day, with no indication of probable change.

The chlorine dissolved out of the salt marsh material was at first in the effluent, 600 parts in 100,000, but in six months decreased to 22 parts. The ammonias, at first about 0.10 parts, increased in four months to 0.40, and in the sixth month have reached 1.37 parts; and as no oxidation or nitrification takes place in this material, it is probable that the impurities of the effluent will continue to increase until it becomes as impure as crude sewage.

Saugus Marsh tank No. 4, which contained three and a half feet of peat, underlaid with peaty sand and sand, was kept covered with sewage which settled into the peat; and water held by the material flowed out from the bottom at the following rates per acre per day: 16,000 gallons the first month; 7,400 gallons the second month; 6,000 gallons the third month; 3,600 gallons the fourth month; 4,000 gallons the fifth month, and 3,000 gallons the sixth month.

That some liquid from the sewage has also reached the bottom of the tank is evident from the recent rapid decrease in the saltness of the effluent. The chlorine of the effluent was 1,800 parts per 100,000 the first month; 1,750 the second month; 1,300 the third month; 826 the fourth month; 435 the fifth month, and in the sixth month has decreased to 202 parts.

The ammonias of the effluent, at first 0.1200 parts in 100,000, decreased in the fourth month to 0.0430 parts, and have since been increasing up to 0.2230 parts in the sixth month. There is little change in the nitrates.

Tank No. 5 of Saugus Marsh material contained five feet in depth of peat mixed with some very fine sand and some clay.

During the first month, when kept continually covered with sewage, the effluent was at the average daily rate of 3,400 gallons per acre. In the second and third months it averaged 3,000 gallons per acre, and after applying the sewage intermittently during two weeks, in which the surface was uncovered as much as half of the time, and again keeping it continuously covered, the flow averaged but 360 gallons per acre per day for one month, and 200 gallons per acre per day for the next month.

The saltness of the effluent has not decreased. The chlorine was at first 2,300 parts in 100,000, and in three weeks rose to 2,600 parts, at which it has continued for four months and a half.

The ammonias have remained almost constant at 0.60 parts, and there is no indication that any of the sewage applied has reached the outlet.

Experiments have also been made by the Board, through nearly a year, upon a tank filled with fresh water peat taken from a cultivated field. The tank is seventeen feet in diameter and contains on the bottom underdrains and a bed seven inches deep of coarse gravel, fine gravel and coarse sand, upon which rest five feet in depth of this peat. This material was at first completely saturated with water, by cutting it up fine and sprinkling it into water standing in the tank.

The space occupied by the peat and water was about 8,500 gallons. When the outlet was opened, about 700 gallons of water in one week flowed out of the peat, which settled into the space of about 8,000 gallons. The peat then contained probably as much as 6,000 gallons of water.

The quantity flowing out decreased in a month to about 25 gallons a day, or at the rate of 5,000 gallons per acre per day, although the surface was kept covered with water.

At the end of one and a half months, sewage was applied and kept continually upon the surface. At first, the flow from the tank was at the rate of 4,000 gallons per acre per day. This, in three months, was reduced to 2,000 gallons; after which it decreased but little; and at the end of ten months the flow is a little less than at the rate of 1,700 gallons per acre per day, which is but about one-half of the average daily rainfall upon the same surface.

With 6,000 gallons of water in this mass of peat when sewage was first applied to the surface, it is evident that nearly all of this quantity must flow out before any of the sewage can reach the bottom. With the outlet continually open, only 3,000 gallons of water have flowed out in the ten months since the sewage was first applied; from which we may conclude that the sewage has now reached about half way down the tank. Chemical analyses of the effluent indicate that no sewage has reached the outlet.

The chlorine is no greater than it was when flowing at the same rate four months ago, and is but fifty per cent. greater than when river water was flowing through at three times the present rate. It is now less than one-quarter of the chlorine of the sewage.

The nitrates remain the same as those of the water in the tank into which the peat was sprinkled, and there is no room to doubt that some of the water applied to the tank a year ago still lingers in the lower layers of the peat.

From these experiments we make the following summary: —

Table of Quantities of Water and of Sewage that flowed down through Saugus Marsh Material at the Marsh and in Tanks at Lawrence where the Surface was kept continually covered with the Liquid.

Depth of Peat in the Tank. Feet.	Water applied to the Underdrained Marsh. Gallons per Acre per Day.	Sewage applied to the same Material at Lawrence. Gallons per Acre per Day.
1.5	36,000	22,000 the first month; decreasing to 2,400 in the seventh month.
2.5	66,000	45,000 for two weeks; decreasing to 12,000 in the third month.
3.5	22,000	16,000 the first month; decreasing to 3,000 in the sixth month.
5.0	3,600	3,400 the first month; decreased to 200 in the fifth month.
5.0 of Fresh Water Peat which had been Cultivated.		4,000 the first month; decreased to 1,700 in ten months.

There is good reason to conclude that the flow through the material where the depth of peat was two and a half feet was exceptionally large, — probably due to the peculiar growth. Upon digging up the material at the marsh, after the experiments were concluded, it was found to have a much larger number of roots than the other beds, and the peat became sandy at a less depth than the sample taken between this area and the spaded area. The bed in this material which was spaded up allowed but one-third as much water to pass through as the bed in which the sod was undisturbed.

Excluding this sod area which allowed so large a quantity to pass through, and excluding areas where peat was five feet deep, which allowed much less than the usual rainfall to pass through, we find that the marsh areas, including both sod area and spaded area, where peat was 1.5 feet to 3.5 feet deep, allowed about 30,000 gallons per acre per day of clear water to pass through, but that after applying sewage from five to seven months, only 2,600 gallons of sewage per acre per day would pass through, — an amount which is less than the annual rainfall upon the filtering area, — thus rendering the tract practically inoperative as an area for filtering sewage.

Finding that the turf of the peat 2.5 feet deep both at the station on the marsh, and when placed in the tank at Lawrence, allowed more water to pass through it than would be expected from the experiments upon other sections, it was thought that a peculiar growth of roots, or decayed roots might form channels of communication from the surface to the open sand beneath the peat. To test this, and to determine the effect of a small depth of peat upon a substratum of good filtering sand after the peat had been thoroughly worked over and pulverized, a section one foot in depth was taken from the same place on the marsh where the peat was 2.5 feet deep, and was cut just the diameter of the tank and thoroughly pulverized like garden soil, and put on top of the sand of filter tank No. 11 at the Lawrence experimental station. This sand had been filtering sewage at the rate of 30,000 gallons per acre per day, giving an effluent with but little more organic impurity than that of the water flowing in the Merrimack River. The ammonias for the last month had been .0233 parts, and the nitrates were 1.5 parts in 100,000.

The sand was filled with sewage and the pulverized peat put on top of the sand, and sewage poured upon it till it was saturated. The outlet was then opened and the whole allowed to drain for ten days, after which, the surface being kept covered with sewage, the flow was 2,800 gallons per acre per day. It decreased in one

week to 2,400 gallons per acre per day, at about which rate it continued to flow for one month. During the second month the quantity averaged 1,900 gallons daily. The nitrification was very active with the sand alone. The nitrates, forming 1.5 parts, were reduced upon adding the peat to the surface, and continued for the first month at 0.03 parts. The nitrites, which, with the sand, were 0.003 parts, increased directly to 0.100 and continued for the first month to increase to 0.325 parts; while the ammonias, which, with the sand, were 0.023, with the peat increased to 2.660, or nearly as high as in the applied sewage.

During the second month, the chlorine of the effluent increased to 600 parts, the nitrates averaged .5625 parts, the nitrites averaged .5875 parts, and the ammonias averaged 2.1988 parts, which was 63 per cent. of those of the applied sewage.

The free ammonia was 2.1375 parts and the albuminoid ammonia 0.0613 parts per 100,000.

This peat was found by experiment to contain when saturated 80 per cent. of its bulk of water. When free to settle, after being pulverized, it continues, when underdrained, to hold such a body of water that it appears to be impossible for air to get through it to allow oxidation or nitrification of the liquid, which moves through it at the slow rate of about four inches in depth in a month; but we find, as given above, that in the second month some nitrification does take place, but this is of effluent which has probably been at least a month in coming through the sand beneath the peat, and is there nitrified by means of air which enters through the underdrain. To prove whether this were the case, a water trap was, at the end of the second month, put into the underdrain to check the free flow of air through it, leaving it in the condition of a marsh area when the underdrains are filled with water. This has caused the nitrates to decrease rapidly; but time has not been sufficient to materially change the organic impurities.

This sand, four feet deep, was filtering sewage most satisfactorily at the rate of 30,000 gallons per acre per day, but upon covering it with one foot in depth of pulverized peat, once saturated, the quantity that can be made to flow through the five feet is but 1,900 gallons per acre per day, and the effluent is very nearly crude sewage.

This 1,900 gallons per acre is but one-fifteenth of an inch in depth, and is less than the evaporation; in fact, the amount applied to the surface was more than twice as much as passed through. If an area of this peat thus pulverized were bounded by an impervious dike, so that none of the rain falling upon it could flow off over the surface, it would be kept covered with rain water for more than eight months of the year.

The experiments upon this material prove to the Board that an area of sand covered with peat to the depth of even one foot is unsuitable to be used for a filtration area. They indicate that if so used the surface will become covered with a slime which will prove a nuisance; that sewage applied to such an area in winter will have to remain so long upon the surface that it will freeze and the whole become inoperative; that under the most favorable circumstances the quantity of sewage which can flow through the peat is so small, and the effluent so little improved by passing, that it is not expedient to use it for this purpose; and that the only way to render such an area suitable for filtration is to remove the peat entirely from the sand and apply the sewage directly to the sand.

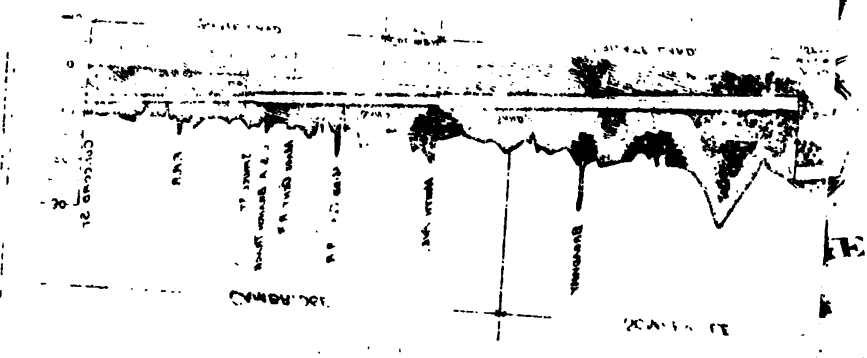
To remove peat from the marsh surface to the depth of one foot would cost as much as four hundred dollars per acre, which indicates that it would be unreasonable to consider the practicability of using the marsh for filtration where there is more than one foot in depth to be removed.

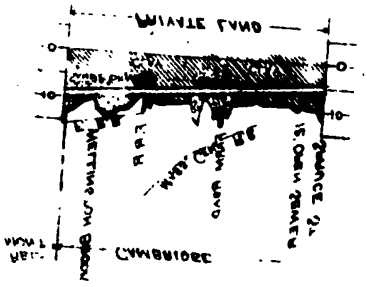
The whole area of the Saugus Marshes, where the depth of peat is not more than one foot, shown upon accompanying Map No. 4, is about 428 acres, of which about sixty acres are in detached pieces, and the remainder is in three distinct areas.

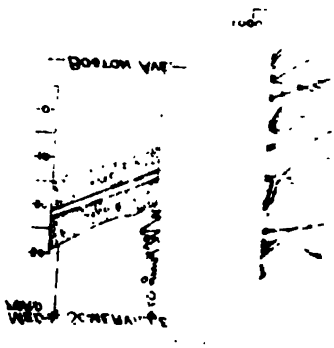
One of these, southwest of Pines River, near Linden Station, contains about one hundred acres with peat six inches to a foot thick, underlaid with sand. Over about one-half the area the sand is very compact, and allows water to percolate very slowly.

Another section, in the vicinity of, and including the Franklin Trotting Park, contains about one hundred and twenty acres, with peat from six inches to a foot deep, much of which is underlaid with perhaps six inches of peaty sand, below which over three-quarters of the area is open sand, which alone at a proper height above tide water would be good filtering material. The other quarter of the area has, beneath, a compact material which allows water to percolate very slowly.

The third section contains about one hundred and fifty acres and is on either side of Bristow Street but mostly north of it. This area is of better material than the others, about thirty acres of it being from two to four feet above the marsh level and covered with soil containing some peat, with very open sand below. This could be used advantageously for filtering, but it is also valuable for agriculture, for which it is said to be worth three or four hundred dollars per acre. Adjacent land is laid out into streets with sewers. This section of one hundred and fifty acres is subjected to a mean height of water greater than the remainder of the marsh, owing to the dam of the Newhall tide mill, which allows







a range of water from high tide to only three or four feet below the surface of the marsh.

The cost of the land and the removal of peat from these tracts would probably exceed five hundred dollars per acre. Diking, underdraining, preparing carriers from the pumping station and returning drains to the pumping station, would probably exceed six hundred dollars more per acre. An indefinite, but considerable expense, must be incurred in diverting and pumping rain-fall coming from surrounding higher land. The cost of pumping ground water and sewage effluent, after the sewage is filtered, would be much larger than was estimated when it was supposed that the marsh material would serve as a filter, and the whole was to be used in one area. And the most that can be expected of the three areas would be the filtration of 20,000 gallons a day per acre on 370 acres, or 7,400,000 gallons, which, at 110 gallons per inhabitant, would serve for 67,000 people.

The circumstances are so unfavorable that it is not necessary to carry the investigation further to see that the expense of preparation and yearly maintenance would be so great as to exclude the use of these areas for filtering the sewage even of the adjacent towns of Malden, Melrose, Everett, and Revere, which, in forty years, would tax the area to its full capacity.

We have to conclude, then, from the additional information obtained by the experiments and investigations of the past year, that the Saugus Marshes will not serve for a filtering area for the sewage of the Mystic Valley; and as there is no other area available for filtering this sewage, its disposal by filtration must be abandoned.

THE NORTH METROPOLITAN SEWERAGE SYSTEM.

We have hitherto considered systems including only the towns of the Mystic Valley, together with East Boston and Winthrop.

From a study of the present demands upon the Boston Main Drainage Works and of their future resources, made by the Chief Engineer of the Board, we find that if the sewage from so large a population as that of Cambridge, Somerville, and Charlestown be added to that of the district which these works were designed to serve, the limit of their capacity will be reached within twenty years.

The Boston Main Drainage Works, — so admirably adapted to dispose of the sewage of the territory bounded by Charles River, Mother Brook and Neponset River for many years, to be relieved when necessity requires, and still serve for the long future the low-

lying parts of this territory, by diverting the sewage of the high parts of the district through other channels not requiring pumping, — would, by the addition to this territory of so large and populous low-lying districts as these cities contain, be overtaxed in a way which could be permanently relieved only by the duplication of the most expensive parts of these works.

In consequence of this the Board has made careful study for a system of sewers, including Cambridge, Somerville and Charlestown with the towns of the Mystic Valley.

Looking at the natural conditions, we find Somerville and Charlestown a little nearer to the outlet at Deer Island, by a practicable route for a sewer, than they are to Moon Island; and Cambridge, a little farther than from Moon Island; but from investigations made in considering the Mystic Valley system it appears probable that the greater distance of Cambridge will be more than compensated by the smaller cost of the Deer Island route.

For the system now to be considered, including the towns of the Mystic Valley, together with Cambridge, Somerville, Charlestown, East Boston and Winthrop, which we designate the North Metropolitan Sewerage System, the only reasonably practicable method of disposal is, the discharge of crude sewage into the sea; for the method by chemical precipitation, which was too expensive for adoption, as compared with this method, when considering the smaller territory, would be so to a much greater degree when a territory containing double the population is included; and the method by filtration upon land cannot be adopted, because there is not sufficient land available to filter one-eighth of the sewage.

We have then first to consider where into the sea, and under what conditions, this quantity of sewage can be poured, at a reasonable cost, with the least resulting discomfort.

Careful study of the tidal currents has been made by running floats from Shirley Gut; from Faun Bar Beacon, which is three-quarters of a mile east from Deer Island; and from Deer Island Beacon, which is one-third of a mile south from the southernmost point of Deer Island and in the north edge of the main ship channel.

For the quantity of sewage to be discharged from the North Metropolitan District, the currents at Shirley Gut are of too short duration and would not carry the sewage beyond adjacent flats. Either of the other sites may be used, but more satisfactory dispersion of the sewage, — because of stronger currents, — and less cost in construction, render Deer Island Beacon preferable. From this locality floats have been run at all stages of the tide to determine the course that sewage will take if discharged here.

From the paths of these floats it is evident that sewage discharged in any desired quantity, from one hour before high tide to four hours after, will not approach any shore where it can give the least offence. It will be carried to sea through the north and south channels never to return.

Careful study has also been made of the results that may be expected if the sewage be discharged here continuously through the twenty-four hours. In this study observations were made upon the sewage discharged at Moon Island, where the rate of outflow during the time of discharge may be called fifteen times that of the continuous flow at Deer Island.

From Moon Island the sewage flows away with the tidal current at the speed of about one mile per hour and spreads to a width of about three thousand feet. One-fifteenth of this quantity discharged continuously at Deer Island, flowing with a tidal current having a greater velocity, will evidently spread to a much less width. If it spreads to one-sixth the extent, or to five hundred feet, the layer of sewage upon the salt water will be much thinner than that from Moon Island, and will more quickly become dissipated. Assuming this to be the width, plottings have been made to show, from the paths taken by twenty floats started at different times during the rising tide, the probable position of the successive areas of sewage starting from the proposed outlet on each hour before and after low water, as they would be at *one* hour from the time of starting and at *two* hours from the time of starting.

These plottings are presented upon the accompanying map of the harbor (No. 2), on which the darker shade represents the position of the sewage within the first hour, and the lighter shade the position within the second hour after starting. As the direction of the current continually changes, the sewage delivered between the hours will be distributed over the whole area between the paths of the floats started upon the hour, as shown by the dotted areas.

The front of the body of sewage at two hours from the time of starting will, from experience at Moon Island, be entirely obliterated, and no appearance of sewage can be recognized farther away than the shaded area upon the map indicates, unless it be an occasional grease-ball or some other small floating substance that has escaped through the racks above the pumping station.

At the Moon Island outlet of the Boston Main Drainage System the sewage collected in eleven hours is generally discharged in a body in about half an hour, and, as stated above, no

sewage is to be found in the tidal current into which it enters two hours after it leaves the sewer. That we might make observations and reach just conclusions in regard to a stream of sewage discharging continuously, the officers in charge of the Boston Main Drainage Works kindly co-operated with the Board by discharging continuously, on a falling tide, for four hours, about 1,500,000 gallons per hour, the equivalent of 36,000,000 gallons per day, which is the amount estimated to be discharged at Deer Island outlet when the population is between 300,000 and 400,000.

When sailing in the stream of sewage, or on the leeward side of it, from near the outlet of the sewer and for a distance of half a mile along the stream, the odor of the sewage was disagreeable. Continuing in the stream of sewage beyond this distance the odor was noticeable for a time, but before reaching the distance of three quarters of a mile from the outlet of the sewer the odor could not be distinguished. At this distance, however, the color of the water was distinctly different from the blue of sea water, — it was more opaque and browner. But there was nothing, at this distance, with wind blowing up stream toward the outlet of sewer, either in appearance or odor, that was in the least objectionable. The appearance of the water here was like that in the upper harbor in midstream, between the Cunard wharf and the New York and New England railroad docks.

By the color and stillness of the surface the area containing sewage could be distinguished for a quarter of a mile farther, or at a distance of one mile from the outlet; but no odor could be distinguished, and there was no disagreeable appearance.

At one mile and a quarter a narrow strip of smooth water and a slightly opaque character of the water, — seen only upon very careful examination, — indicated an effect from sewage; but at one and a half miles from the outlet no trace of the sewage could be seen, although floats which started with the sewage had gone far beyond.

To present this subject with more definiteness than can be conveyed by recording the observations of individuals, samples of the water taken from the middle of the stream of sewage were subjected to most careful chemical tests, in comparison with the adjacent salt water which was unaffected by this sewage, and with the salt water of the inner harbor.

Samples of the sewage throughout the stream of observable sewage and beyond were taken within eight inches of the surface, after the stream had flowed in nearly the same place for three hours, and were subjected to chemical analysis with the following results: —

	Free Ammonia.	Albuminoid Ammonia.	Sum of Ammonias.	Chlorine.
Salt water, up stream, from area containing sewage,	.0056	.0098	.0154	1,675
Salt water, down stream, from area containing sewage,	.0056	.0095	.0151	1,746
Water, within area containing sewage, at the following distances from outlet:				
400 ft.,	2.5000	.5310	3.0310	773
1,600 ft.,	.1944	.0636	.2580	1,570
3,200 ft.,	.0416	.0254	.0670	1,621
4,700 ft,	.0224	.0116	.0340	1,694
6,200 ft.,	.0184	.0156	.0340	1,689
7,200 ft.,	.0136	.0108	.0244	1,687
9,200 ft.,	.0104	.0096	.0200	1,710
Water in mid stream at crossing of North Ferry to East Boston,	.0480	.0154	.0634	1,581

From these analyses it appears that in the stream of sewage at four hundred feet from the outlet of the sewer the upper eight inches in depth was about one-half sewage. At 1,600 feet distant it contained about one-eighteenth of its bulk of sewage, and at 3,200 feet, or five-eighths of a mile distant from the outlet of the sewer, the ammonias indicated the amount of sewage added to be but 1 per cent. of the volume of the water, and the same amount as found in mid-stream at the crossing of North Ferry to East Boston. Beyond this distance the amount of ammonia added became about one-half of 1 per cent at a mile, and less than one-tenth of 1 per cent. at one and four-fifths miles from the outlet.

These results confirm those of direct observation. With the ordinary wave motion at this place, a mile from the outlet, the amount of sewage remaining near the surface of the water is so small that no disagreeable appearance or odor can be recognized.

From these experiments and the position of the currents shown upon the map, it is evident that the sewage discharged continuously at Deer Island Beacon will not reach any shores, nor lodge upon any flats that are exposed at low tide, nor come into the neighborhood of any dwelling, nor of land that is capable of being used for dwellings in the future, unless it be on a portion of Deer Island.

To guard against deposits of heavy material near the proposed

outlet, provision has been made in the designs, and the cost of operating included in the estimates, for removing at each of the pumping stations and at the river crossings whatever material of this kind may get into the sewers.

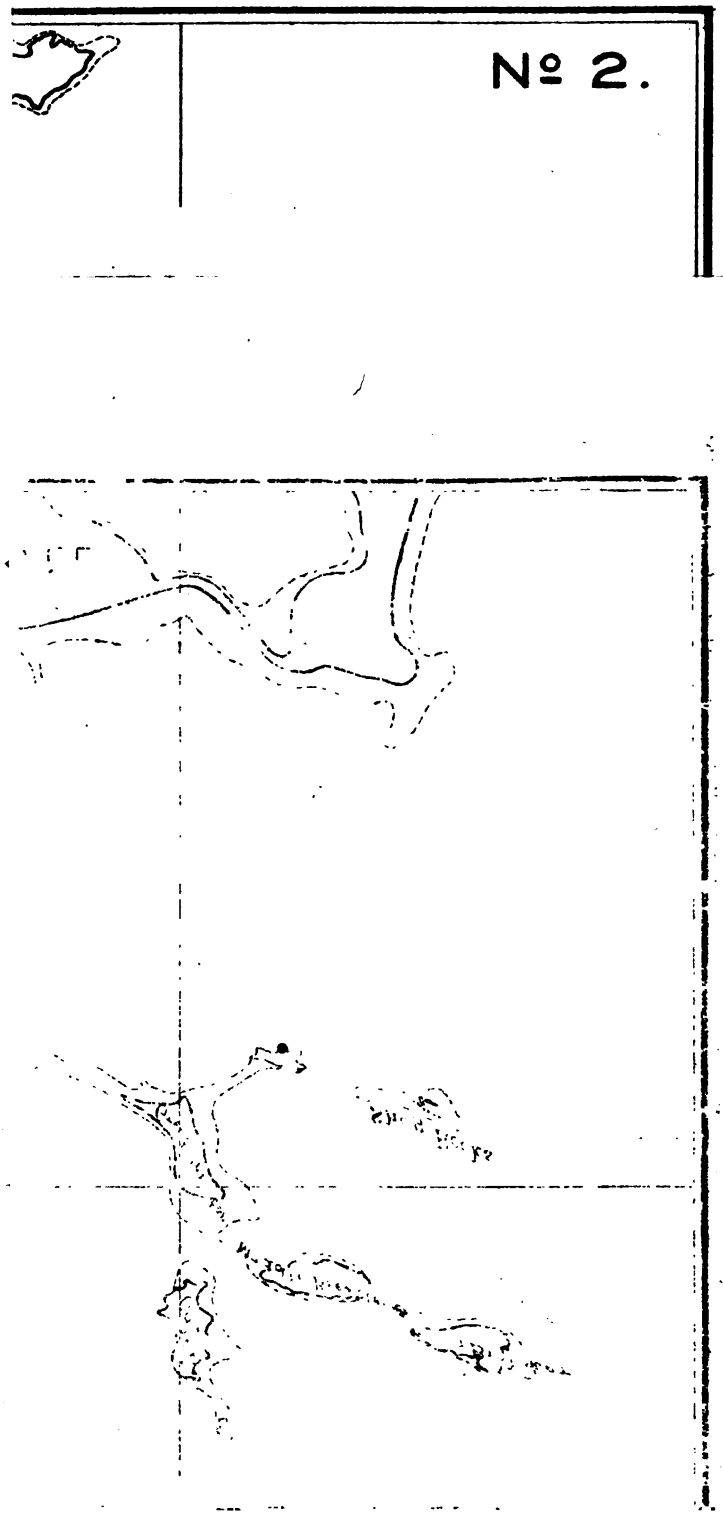
This material will come principally from the street washings of the cities which now have the combined system of sewers, and will be removed, by sand pumps or other contrivances, from places where it has been allowed to settle.

The outlet at Deer Island Beacon is directly into a tidal current more than fifty feet deep, in which the velocity of more than two and a half miles per hour is much greater than that in the sewer, and the scouring effect of the currents, reversed twice daily, will readily remove everything which the sewer can bring there. This conclusion is confirmed by the experience at Moon Island, — where the maximum velocity of the tidal current is much less, — given in the annexed report of the chief engineer of the Board.

As a result of this study, the Board has concluded that it is advisable to construct the sewage works to discharge continuously the comparatively small stream of sewage as it arrives at the outlet. Should the time ever come when such a discharge proves objectionable, and the objection can be removed by holding the sewage back for one, two, or three hours after low tide, the capacity of the sewer between East Boston and the outlet will for several years be sufficient to allow of such storage during the hours named; and if it becomes desirable to store the sewage through the incoming tide and discharge it only when the outgoing tide will carry it directly to sea, a reservoir can be then built on Deer Island as well as at the present time; but the Board does not anticipate the need of such a reservoir.

In the Resolve, Chapter 95, of 1887, two classes of sewers are designated. One class, called "The trunk line and main branches," is to be located, and its probable cost of construction and annual expense of operating are to be determined. The other class, expressed by the words, "The main lines by which each city or town may provide for itself a system of sewerage and drainage, with its outlet into said trunk line and main branches," is to be located, but the cost is not to be estimated.

The intention of the General Court as to what should be included in each class has been a subject of careful consideration by the Board. The words of the Resolve appear to imply that the special system for each city or town should include all the main lines of sewers built for the sole use of that city or town and lying within its own territory, in which case the general system of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M A
M E D F O R D
S O M E R V I L L E
CAMBRIDGE
EAST
CAMBRIDGE
CAMBRIDGEPORT
C H A R L E S
B R I G H T O N

trunk line and main branches, extending across the whole width or length of the interior towns of the system, would enter the outlying towns but a few feet only at one or more points, sufficient to give outlets to their special systems. This would exclude from the trunk line and main branches, and, from the estimates of cost, all of the great intercepting sewers of Cambridge, Charlestown and East Boston which have been included in the several reports previously presented to the General Court as the main branches of a general metropolitan sewerage system, having for their object not merely to serve the communities whose sewage they convey, but to relieve the waters of the great metropolitan district of the impurities now being poured into them.

It has been concluded, that, if the General Court had intended to exclude from the general system of trunk line and main branches these intercepting sewers, and thus include them with the main lines of the special systems, for which they ask no estimate of cost, such intention would have been expressed more definitely in the instructions given to this Board. Estimates have therefore been made of the cost of these intercepting sewers, and they have been included in the general system of trunk line and main branches; but the estimates of cost have also been grouped to indicate the cost of the general system with these intercepting sewers excluded.

The territory included in the North Metropolitan Sewerage District is shown upon Map No. 1, bounded upon the land side by the broad buff line. There are areas in nearly all of the adjoining towns which may at some future time find outlets into this sewerage system. These areas are generally included between the broad buff line and an irregular dotted line upon the map, which is the boundary of the Mystic Valley. They are sparsely settled and do not at present need an outlet for sewers.

The general sewerage system is shown upon the map by red lines. The most distant point is seventeen and a half miles from the outlet, near the line between Stoneham and Woburn. Here the sewer is about forty-eight feet above low tide, and the diameter is one foot and three inches. At this and at other points throughout its length the height of the bottom of the sewer above low tide in feet and tenths is given upon the map in blue figures, and the diameter of the sewer in feet and inches is given in red figures. It is not intended that the sewers shall in all cases be circular, but they are intended to be of capacity equivalent to circular sewers of the diameter given.

The sewer extends down the valley through East Woburn and Winchester Highlands to the Mystic Valley sewer built by the city

of Boston. Here it receives two fifteen-inch branches from Woburn, and continues along Abbajona River in Winchester — by the sewer already built and by new work in Medford — to West Medford, where its grade is eight feet above low tide, and diameter is 3 feet 2 inches. Here it receives sewage from the Alewife Brook branch, and continues through Medford Centre and Wellington to Malden River, with diameters increasing from 4 feet 4 inches to 5 feet, and the bottom of the sewer reaches the level of low tide. Passing under Malden River by two iron pipes 30 inches in diameter, which are depressed about 6 feet below the general line of the sewer, it continues 5 feet in diameter through Everett to the Saugus Branch Railroad. Here it is met by the branch from the eastern part of Stoneham through Melrose and Malden, bringing the sewage of these towns and having diameters increasing from 10 inches to 3 feet and 4 inches. The main sewer goes on 5 feet 6 inches in diameter to Broadway in Everett, where it receives from the south the Cambridge branch and is enlarged to a diameter of 8 feet and 2 inches, with the bottom 6.3 feet below low tide. It then continues about two miles and one-third through Everett and the western and southern part of Chelsea to Eastern Avenue, having its diameter increased to 8 feet 5 inches. Here a branch comes in along Eastern Avenue, bringing the sewage from the northern and eastern parts of Chelsea.

The Chelsea River is then crossed by two lines of cast-iron pipe 4 feet in diameter, situated between the highway and railroad bridges. The brick sewer then continues to Addison Street, receives the main intercepting sewer of East Boston, is enlarged to a diameter of 9 feet, and, crossing the Boston and Albany Railroad, reaches the East Boston Pumping Station with the bottom of sewer 12.8 feet below low tide.

The sewage of all the towns through which the main sewer has passed — in fact, of all the towns north of Mystic River — is received and brought to East Boston without pumping.

Of the cities and towns south of Mystic River, the sewage of Arlington and Belmont and the west end of Cambridge and Somerville, and a small section of Medford, brought by the Alewife Brook branch, with diameters from 1 foot 6 inches to 3 feet 2 inches, will be pumped the height of about 14.6 feet into the main sewer; and the sewage from Charlestown and from the larger part of Cambridge and Somerville and a small part of Medford will be brought by the Cambridge branch, which, starting at Mt. Auburn Street in Cambridge about 6 feet above low tide with a diameter of 2 feet, borders Charles River, with increasing diam-

eter, and crosses over through Somerville to a pumping station at the south end of Malden Bridge on Mystic River, receiving branches from Charlestown and Medford, and attaining a diamater of 6 feet 8 inches, with its bottom 11 feet 7 inches below low tide. The sewage is here raised by pumping 14.4 feet. and is conveyed under Mystic River by two iron pipes 40 inches in diameter, and continued in a brick sewer 6 feet in diameter to the main sewer in Everett.

At East Boston the sewage of all the towns except Winthrop is pumped to the height of about 15.9 feet and conveyed in a brick sewer 9 feet in diameter, having its invert 3.1 feet above low water at the upper end, and passing through Breed's Island and Winthrop to another pumping station on Deer Island, distant about five miles, where the invert is about 8 feet below low tide. Belle Isle Inlet and Shirley Gut are each crossed by two iron pipes 4 feet in diameter.

At Deer Island Pumping Station all of the sewage is to be pumped a height varying with the height of the tide, — from 10 feet to 14 feet. It is conveyed along the island 1,000 feet through a sewer 6 feet wide and of varying height, and then through two iron pipes 4 feet in diameter buried on the harbor side of the bar below low water for a distance of about 2,000 feet, and rising near the end to a few inches above low tide at the outlet, which is a little west from Deer Island Beacon. Here, on the north border of the main ship channel, the ends of the pipes will be encased in a heavy wall of masonry, off against which the bottom rapidly slopes to a depth of more than 50 feet below low tide.

In twenty-five or thirty years the system will need to be enlarged by an additional siphon pipe at Belle Isle Inlet, and one at Shirley Gut, each 4 feet in diameter, and by an additional outlet pipe at Deer Island, also 4 feet in diameter, and by additional pumping machinery. In other respects the system is at first to be constructed of ample capacity to serve the district for forty years.

Much more time than usual has been spent, under the direction of the Board, in making designs of the work complete, in order to present estimates of cost, which include all the work necessary to be done. These designs have been made by Mr. Carson, in consultation with the Committee of the Board having this matter in charge and with the Chief Engineer of the Board. Mr. Carson was the principal superintendent of construction of sewers of the Boston Main Drainage Works, and was more intimately acquainted with all of the difficulties to be met in similar work in the North

Metropolitan District and with the cost of overcoming them than any other engineer. He made all of the estimates of cost.

These were reviewed by Mr. Joseph P. Davis, the Consulting Engineer of the Board, and by Mr. F. P. Stearns, the Chief Engineer of the Board. Mr. Davis designed the additional water supply of Boston, and constructed it within the cost which he had estimated; he also designed the Boston Main Drainage Works, which were constructed under his direction until he resigned in 1880. Mr. Stearns was one of the assistant engineers on the construction of the Boston Main Drainage Works from 1880 to 1885, after which he had charge of operating the system until he became Chief Engineer of the State Board of Health.

These engineers examined the whole course of the trunk line carefully upon the ground with Mr. Carson, and reviewed the estimates, item by item, with the data which Mr. Carson had accumulated by his surveys and soundings, and the additional data which Mr. Clarke, the Engineer of the Massachusetts Drainage Commission of 1885, had accumulated; and they concluded that the estimates of Mr. Carson were reasonable, and the amounts adequate for the proper construction of the work.

We, therefore, present the result of these estimates with confidence, as expressing all that need be expended in constructing and furnishing the complete works if built under careful business management with present prices.

Detailed estimates of cost may be found in the report of Mr. Carson. The estimated cost of the whole work of trunk line and main branches with outlet, with pumping machinery and all furnishing necessary for disposing of the sewage of the North Metropolitan District when the population is 290,000, — which is the estimated population in 1892, — inclusive of the intercepting sewers of Cambridge, Charlestown, Chelsea and East Boston, is $4,159,453.

The additional expense in construction to make the system capable of disposing of the sewage of the district forty years hence, when the population shall have reached 513,000, will be due to the increased pumping capacity and to additional outlet and siphon pipes, amounting to $224,400; making the total cost for construction up to 1930, $4,383,853.

The yearly maintenance, including all running expenses and repairs, is estimated to be: —

With a population of 290,000, . . .	$84,700 00
With a population of 513,000, . . .	116,200 00
Or an average for forty years of . . .	$100,450 00

If the money for construction were raised upon the credit of the Commonwealth, with a sinking fund running forty years, the rate of interest would probably be three and one-half per cent., and the sinking fund, with incidental expenses, one and one-quarter per cent., — making the yearly amount to be paid for interest and sinking fund four and three-quarters per cent.

The yearly payments for interest and sinking fund will then be: —

Four and three-quarters per cent. of $4,159,453 =	$197,574 00
The yearly maintenance with 290,000 people as above =	84,700 00
Total yearly payment =	$282,274 00

Or a little less than one dollar a year per inhabitant; and this yearly payment will decrease year by year with the increase in population, until — taking account of the expenditure for enlargement and increased pumping expenses — the rate of annual payment will be reduced in the latter part of the forty years to less than sixty-six cents per inhabitant.

The apportionment of the cost to the several communities was not committed to this Board, and we make the above statement simply to show that the average cost per inhabitant of the construction, maintenance and all running expenses for forty years, together with interest and the final payment of the debt, will amount to about eighty cents per year for all of the sewers shown by red lines upon the accompanying Map No. 1, which include the intercepting sewers of Cambridge, Charlestown, Chelsea and East Boston.

The cost of these intercepting sewers is as follows: —

Cambridge,	$306,470 00
Charlestown,	121,761 00
Chelsea,	34,650 00
East Boston,	143,413 00
Total,	$606,294 00

If these are not included in the trunk line and main branches, the cost of the trunk line and main branches, which will give an outlet within its own territory for all considerable sections of every city and town included in the system, will be $4,159,453 less $606,294, or $3,553,159 in 1892, and $3,777,559 in 1930.

In the judgment of the Board one of the elements which should enter into the apportionment of the annual running expenses to the several communities is the quantity of sewage supplied by

each which has to be pumped. To provide for determining these quantities, methods of measuring have been devised and the consequent additional cost of the system and of yearly expense have been included in the estimates of cost.

Where the existing or proposed systems of sewers in any city or town discharge at points widely apart, which cannot reasonably be connected by a line of sewers lying entirely within the city or town, a main branch has generally been extended to each of such districts, so that each city or town may find an outlet for the sewers of all considerable sections included in the system into the trunk line, or a main branch, without going beyond its own territory.

There are, however, in several towns small sections which may be drained by pipes less than ten inches in diameter which can most economically be made a part of the system of an adjoining town. To such small areas main branches have not been extended, but they have been left for neighborly adjustment between the towns.

While the cities and towns are to provide for themselves systems of sewers having outlets into the trunk line, it is plain to the Board that the authority which constructs and controls the trunk line should extend for certain purposes over the whole system of sewers in each of the cities and towns.

This authority should be competent to limit the quantity of sewage that may enter the trunk line from any quarter, especially to prevent the entrance of large quantities of storm water, that the whole system may not be flooded and great damage result. To this end the design and construction of the intercepting sewers in the cities having sewers which receive storm water, and of the connections with them of the existing or of future sewers, should be subject to its approval.

While all new systems should be designed to receive sewage only, the authority should be competent to have this design carried out, and, when necessary, to prevent the entrance of storm water.

The authority should also be able to limit the quality of material entering the trunk line so far as to exclude material which the ordinary current in the sewer cannot carry along. It is not sufficient that the authority should have power to remove gravel and sand and the heavy solid material of manufacturers' waste after it enters the sewers, but it should be competent to require the entrance to the sewers in the several cities and towns to be so made and maintained that the objectionable substances may not enter.

By comparing the plans and profiles of the trunk line now proposed from East Boston to the Deer Island Beacon with the state-

ments made concerning a route to this outlet on pages 139 to 142 of the report of the Massachusetts Drainage Commission, it will be seen that many of the difficulties mentioned therein have been avoided by the more extended examinations of this Board.

Knowledge of the tidal currents enables us to dispense with the costly reservoir. The conduit twelve feet in diameter, and the massive wall of cut stone masonry one-third of a mile long, from Deer Island to the Beacon, therein proposed, are replaced by two iron pipes four feet in diameter, placed underground on the inside of the bar where the waves have lost their force. The expensive structure across long reaches of marsh is avoided by changing the line to one mostly through hard land, and by having two pumping stations of low lift instead of one with high lift, so that the sewer may lie in the ground at moderate depth.

The result of these and other changes, and of including a larger territory to discharge at this outlet, is that instead of the method of disposal which we have adopted being more expensive than the method of filtration upon Saugus Marshes therein proposed, we find the cost per inhabitant of the plan now proposed is about eighteen per cent. less than the estimated cost per inhabitant of the plan for Mystic Valley presented by that report.

As soon as the Board had concluded upon the best method of disposing of the sewage of the cities and towns which, collectively, are here designated as the North Metropolitan Sewerage District, and had completed plans and estimates of cost of the trunk line and main branches, and had completed plans for sewers for all of the cities and towns which have no sewerage systems, and so was enabled to determine what cities and towns and parts of cities and towns should constitute said sewerage district, notices were sent to the authorities of all of these cities and towns in the following words: —

COMMONWEALTH OF MASSACHUSETTS.

OFFICE OF STATE BOARD OF HEALTH,
13 BEACON STREET, BOSTON, Oct. 13, 1888.

To the Mayor or Selectmen of the City or Town of _____.

The State Board of Health, in pursuance of the requirements of section 7 of chapter 95 of the Resolves of the year 1887, hereby gives notice that it has determined that the cities of Cambridge, Somerville, Chelsea, Malden, and the parts of the city of Boston known as Charlestown, East Boston, Breed's Island and Deer Island, and the towns of Belmont, Arlington, Winchester, Medford and Winthrop, and parts of towns, as follows: Woburn, except 190 acres in the west and southwest quarters, in the Shawsheen River drainage area; Stoneham, except 260 acres in north quarter, in the Saugus River drainage area; that part

of Melrose which drains into Mystic River and into Pines River, including 2,196 acres, and excluding about 707 acres of the easterly side of the town which drains into Saugus River; and Everett, except 240 acres in the northerly quarter which drains into Pines River, mostly occupied by Woodlawn Cemetery, constitute the sewerage and drainage district to be reported by this Board under said Resolve.

Enclosed is a plan showing the general position of the proposed trunk line and its main branches, which may serve as an outlet for a system of sewerage for each city and town.

Plans showing the proposed method of utilizing these outlets for each city and town may be seen, and will be explained by an engineer of the Board at the office, No. 13 Beacon Street, Boston.

The Board will be in readiness to confer with each of said cities and towns with respect to such drainage and sewerage system at Room 10, at the State House, on Tuesday, Oct. 23, 1888, at 10 o'clock A.M., and will, upon the request in writing of any city or town, thereafter give a hearing to said city or town upon such questions relating to the method of its utilizing said trunk line and main branches as said city or town may submit, in writing, with such request.

The Board will also, upon request of any city or town, give a hearing upon the question whether said city or town can more advantageously provide for itself a system of sewerage and drainage by itself and not as a part of said general system.

By order of the Board,

SAMUEL W. ABBOTT,
Secretary.

HENRY P. WALCOTT,
ELIJAH U. JONES,
JULIUS H. APPLETON,
THORNTON K. LOTHROP,
FRANK W. DRAPER,
HIRAM F. MILLS,
THEODORE C. BATES,
State Board of Health.

Each of these notices was accompanied by a plan of the district, like Map No. 1 of this report, showing the trunk line and main branches of the sewerage system, as there presented in red lines.

At the meeting on October 23, the cities and towns appeared to be very generally represented. The general features of the plan which the Board had adopted were presented by the chairman of the Committee upon Water Supply and Sewerage of the Board. Many questions were asked and answered; but no changes were suggested, except that a representative from Revere, finding this town was not included in the system, desired to know what provision could be made for Revere. As this town was not in the territory designated by the General Court for this investigation, and was not on the direct line to the outlet, it had not been included in the system; but it is entirely practicable to con-

nect it with the system, by lowering the grade of the intercepting sewer on the east side of Chelsea and extending it to Revere.

A survey and estimate of cost since made by the Board show that the Chelsea branch sewer through Eastern Avenue can be lowered and extended parallel with the Boston and Maine Railroad across the stream into Revere at a height which will receive the sewage of Revere, for an expenditure of $86,000 in addition to that already given for the Chelsea branch.

At the meeting for conference at the State House, there was presented, in addition to the general plans accompanying this report, a special plan of each city and town in the district, showing, for each city having a system of sewers, the method of connecting the main lines of that system with the trunk line or a main branch of the general system; and for each city and town which has not already a system, there was presented a complete plan for a system of sewers, indicating a method of conveying sewage from all of the streets, which will need sewers for many years, to the trunk line or a main branch of the general system.

The main lines of these special systems have since been placed on Map No. 1 in blue, with blue figures giving the height of the bottom of the pipe above mean low tide.

These special plans of each town are not intended for publication with this report, but are to be kept on file by the State Board of Health, or at such other depository as the General Court may direct, for additional information for each of the cities and towns when providing for itself a system of sewerage with outlets into the general system.

The Board has had examinations made of the several towns, to determine if it will be more advantageous for any town within the district to provide for itself a system of sewerage by itself, and not as a part of the general system.

It is plain that for the interior towns the only other method available is filtration through land, where suitable land can be found which can be reached economically, and where such use will not be objectionable to the inhabitants. All of these conditions were not found in any of the towns. The nearest approach to them was in Stoneham and in Woburn; but after a preliminary investigation the Board concluded it would be better for these towns to join with the others in the general system.

Upon notifying the several towns that the Board would, upon request, give a hearing upon this question, no requests were received.

For complete sewerage of Winthrop in the future, the general

system presents advantages in grades, in cost of pumping, and in removing the sewage to a distance which will be unobjectionable, that would make this outlet preferable to any which the town can provide for itself; but for the immediate relief which Winthrop requires, and until it becomes necessary to pump its sewage, it will probably be cheaper for the town to take care of its own sewage.

The Board is unable to decide more definitely upon this point until the principles of the apportionment of cost to the several cities and towns are determined.

Outlet Sewers for the Lower Valley of Charles River.

For the cities and towns of the lower valley of Charles River which are not included in the North Metropolitan Sewerage District, this Board is "requested to designate some method for the disposal of the sewage."

These cities and towns are Waltham, Newton, Watertown, the Brighton District of Boston, and Brookline.

Waltham, being so far removed from either outlet, — being thirteen and one-half miles from Moon Island outlet, and eighteen and one-fourth miles from Deer Island Beacon, by a practicable route for a sewer, — was examined by Mr. Ball to see if suitable filtering area could be found sufficiently near for disposal of its sewage. The only areas found adapted to this purpose were near the south-easterly line, partly in Waltham and partly in Watertown; but their proximity to the filter gallery from which Watertown takes its water supply rendered their use inadmissible, and the Board decided that a proposed method of chemical precipitation and discharge of the effluent into Charles River below the dam in Watertown, but above long reaches of flats uncovered at low tide, ought not to be permitted.

The northerly part of Newton and Watertown are similarly situated, and the Board finds no satisfactory means of disposal of the sewage of the thickly settled parts of these cities and towns except by conveyance through Brighton and Brookline to Moon Island outlet through the intercepting sewer of the city of Boston, — a distance from Newton east line of eleven and one-fourth miles, — or by conveyance through Brighton to the proposed intercepting sewer in Cambridge and thence to Deer Island outlet, a distance of sixteen miles. The latter course would render necessary the enlargement throughout its whole length of the thirteen miles of intercepting sewer from the entrance in Cambridge to Deer Island, to provide for this increase of about thirty per cent. in the quantity flowing; and on account of the greater distance, this additional sewage would necessarily be pumped nearly ten feet higher than if taken to Moon Island.

These conditions indicate very decidedly that the most natural course is to take the sewage of this district to Moon Island. Brighton sewage will of course be carried in that direction by the city of Boston; and no question can arise in regard to this being the proper outlet for Brookline. The intercepting sewer of Boston was built with the intention of receiving, for the long future, the "low-level" sewage of the district bounded by Charles and Neponset rivers and Mother Brook, and was designed to be of ample size to convey the sewage of 800,000 people and two-thirds as much rain water when running half full. It will be more than fifty years before this population is reached in both the "high-level" and "low-level" territory of this district, if Waltham and Watertown be included therein.

Investigations made by the chief engineer of the Board, report of which is appended, show that, with the additions made, which were contemplated in the original design of the Boston Main Drainage Works, their ability to dispose of the sewage of the whole territory just described will, during the next forty years, be somewhat greater than their present ability to dispose of the sewage they now receive, provided the amount of storm-water they receive is not increased.

The Board recommends that arrangements be presently made with the city of Boston to receive into its intercepting sewer the sewage of Brookline, Newton, Watertown and Waltham, and that the work of an extension to Waltham be accomplished at the earliest date practicable.

The Board herewith presents a plan for such extension designed to convey, when running full, thirty cubic feet per head on the estimated population in 1930, this quantity being as much as the Boston intercepting sewer will then be in a condition to receive from this quarter. This thirty cubic feet per person is the same amount that the sewers in the North Metropolitan District are designed to convey.

It is intended that storm-water shall be excluded from all new systems of sewers, and from sections of existing systems, entirely new, connecting directly with the intercepting sewer; and that its entrance to the intercepting sewer from systems of sewers already built shall be strictly regulated.

It was not contemplated that complete surveys should be made of these cities and towns to show how systems of sewers may be arranged in each; but examinations have been made which show that sewage may be brought to the main sewer from all parts of them excepting 105 acres in Newton, 86 acres in Waltham, and 86 acres in Watertown of unoccupied and mostly marsh land bor-

dering the river, and excepting a large tract in the south-west end of Brookline of about 1,486 acres, including Walnut Hill, which is sparsely settled and which is beyond the ridge and slopes away from the proposed sewer. When this district shall need sewers, they will find an outlet into the Boston system through West Roxbury, probably by the valley of Stony Brook.

The estimated cost of the main sewer from Waltham to the intersection of Huntington Avenue and Camden Street in Boston is $804,243.

This sewer is shown in plan and profile upon Map No. 3. Its line is substantially the same as that designed by the Massachusetts Drainage Commission. Its grades have been somewhat lowered near the upper end to receive sewage from lower and more distant points in Watertown, and the size is somewhat reduced. Near the lower end, within the city of Boston, the diameter is also somewhat reduced because the sewage from Cambridge is not now brought in this direction.

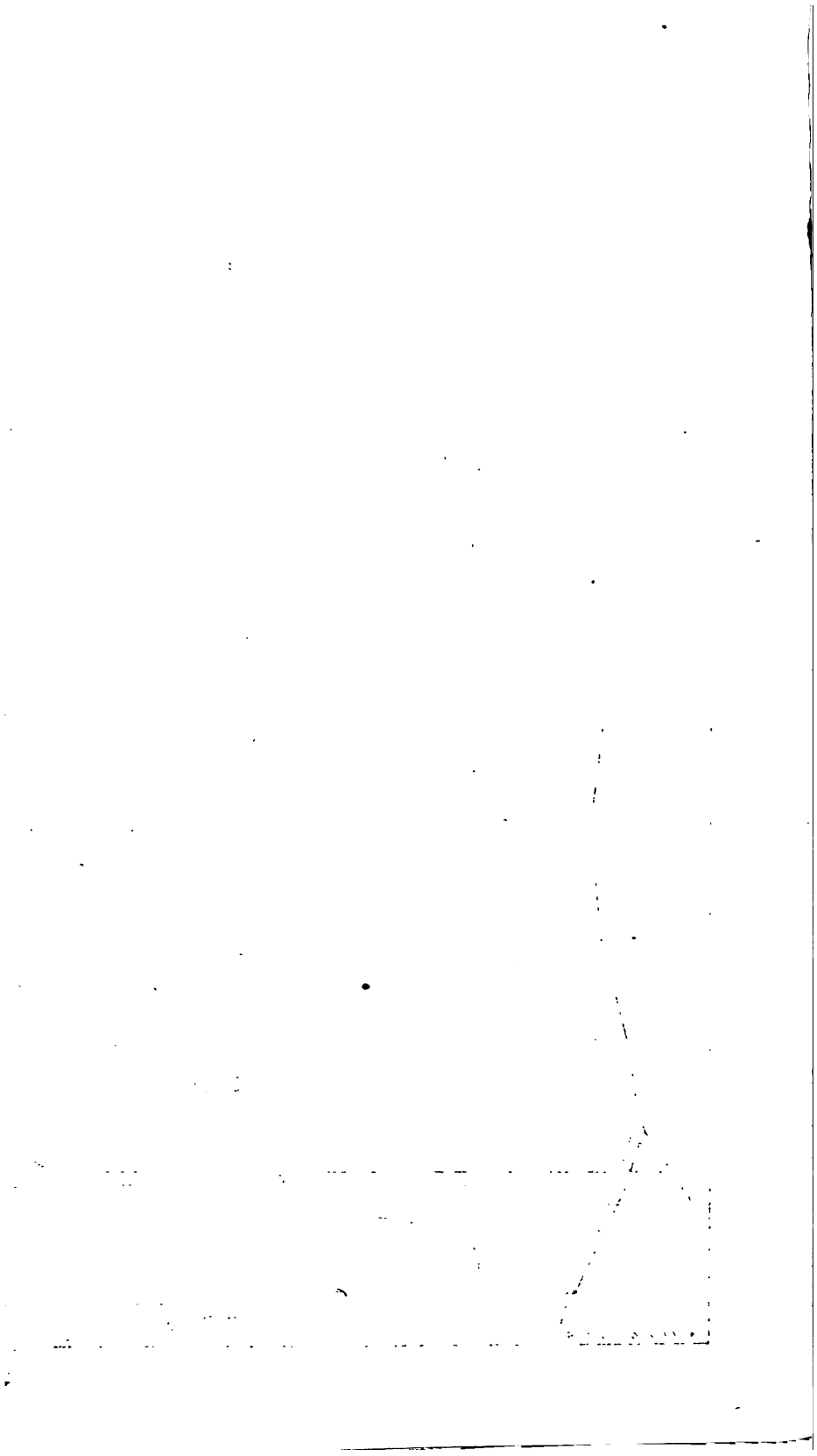
The final reports of the several engineers who have aided us in making the investigations, and reaching conclusions upon the important questions herein discussed, are appended; and the Board desires to express its cordial appreciation of their zeal and ability, and the thoroughness of their work.

We have thought it unnecessary to dwell upon the vital importance of providing relief for the several communities included in the two populous districts, because the action of the General Court in directing this Board to consider, not whether such relief is required, but how it can be wisely accomplished, indicates that the people of the State have grown to appreciate the necessity of action, and desire only to be shown the best method of accomplishing the purpose.

To this problem we have devoted our energies with results which we are gratified to present. These show that complete relief can be reached by expenditures which can reasonably be made by the populous and wealthy communities interested in the healthfulness of this great metropolitan territory.

HENRY P. WALCOTT,
ELIJAH U. JONES,
JULIUS H. APPLETON,
THORNTON K. LOTHROP,
FRANK W. DRAPER,
HIRAM F. MILLS,
THEODORE C. BATES.
State Board of Health.

No 3



REPORT OF CONSULTING ENGINEER.

HIRAM F. MILLS, Esq., *Chairman of Committee, State Board of Health.*

DEAR SIR: — In your communication of the 12th inst., you state that the committee of the State Board of Health, having in charge the question of disposal of sewage of the Mystic and Charles river valleys, has, during its investigations, frequently consulted me in regard to the important questions that have arisen, and request an expression of my opinion on the following points: —

The wisdom of the general schemes recommended by the committee for disposal of the sewage; their adequacy to relieve these valleys; whether there is any other practicable method of accomplishing these results without largely increased cost; the propriety, in the light of the investigations made by the Board, of discharging the sewage of Cambridge, Somerville and Charlestown into the present Boston system; the satisfactory disposal of the sewage of the North Metropolitan District, without nuisance or deposit, by continuous discharge near Deer Island Beacon; the location of the trunk line of this system, and the reliability of the estimates of cost.

I think there can be no question that the best method of disposing of the sewage of Newton, Waltham, Watertown and Brookline, in the valley of the lower Charles, is to intercept its flow to the river and convey it to the main sewer of the Boston system. The alternative to this seems to be to convey the sewage to some point on the river below Watertown, and there subject it to the precipitation process; but this is not to be recommended, not only on account of the large cost of operating such works, but also because, owing to the flow of the tides, the but partially purified effluent would be some days in reaching the outer harbor.

It has heretofore been proposed to also convey the sewage of Cambridge, Charlestown and Somerville to the main sewer of the Boston system, and this, indeed, is a desirable way of disposing of it; but a very careful study of the probable future population of Boston and these cities, and the quantity of the sewage to be taken care of, recently made by your chief engineer, Mr. Stearns, indicates that if this were done, the full capacity of

the present system would be reached in a very few years, — so few that Boston could reasonably and undoubtedly successfully oppose such disposal. The recent Boston records show a much larger average discharge per capita than was anticipated or than it has heretofore been the practice to estimate upon. The chief causes of this are the large water consumption and the large leakage of ground water into the sewers. These are remediable (or at least partially so) defects of supervision and construction, but it would not be prudent to assume that the remedy will be applied; and even if applied, the great cost of a high-level sewer would be thrown upon the city at a comparatively early period, were the sewage of all the cities of the lower Charles permitted to enter the present system. I have reviewed the study made by Mr. Stearns upon the above-mentioned points, and believe that the facts he has collected justify these conclusions. I am of opinion, therefore, "in the light of the investigations made by the Board," that it would not be wise to discharge the sewage of Cambridge, Charlestown and Somerville into the Boston system.

This being admitted, and having in view the topography of the district and the financial considerations, it will be seen that the sewage of these cities should be united and disposed of with that of the cities and towns of the Mystic valley. You have had made by competent engineers studies of three methods of disposing of this sewage; viz., by precipitation, by land filtration, and by discharge into the sea in a crude state.

The discharge into the lower Mystic after chemical treatment, although it would in part alleviate the present growing evil resulting from discharge at many points in a crude state, could not be made without causing, at times, some nuisance at the precipitation works, and possibly also along the shores of the Mystic, by the decomposition of the effluent after it had entered the river, as, owing to tidal action, it would not be at once carried out to sea.

But, aside from this consideration, the large yearly cost of operating is a sufficient objection to adopting a scheme of this kind so long as other methods of disposal are available.

The only large tract of land available for irrigation or filtration is in Saugus and Revere, south of the Saugus River. A large portion of this land is covered with salt-marsh peat, which the experiments made under your direction during the past year in the field and at Lawrence show not to be a good filter, either as regards the quantity of liquid passed or the character of the effluent. I had thought that by preparation of the peat surface, and

by methods of application of the sewage, somewhat different from those usually employed, the peat land might be used with advantage; but the experiments above mentioned point to a different conclusion.

However, even were this land moderately well suited for the purpose, there is not enough of it to care for the sewage of so large a population as the valley of the Mystic and the cities of Cambridge, Charlestown and Somerville will contain in the not distant future.

There remains for consideration the practicability of disposing of the sewage in its crude state at some point where strong currents exist that will quickly dilute and disperse it.

A strong tidal current sets through Shirley Gut, and the discharge of the sewage at this point has been recommended; but more recent float experiments show that the current loses its force soon after passing the Gut, and give evidence that sewage deposits would be formed at Winthrop Beach and along the north-easterly shore of Deer Island. In view of these experiments, this cannot be regarded as a favorable point for discharge.

Another strong tidal current makes in the main ship channel between Deer and Long islands, and this channel can be reached by a discharge sewer running under the surface of the bar which unites the Deer Island Beacon with the island itself. This is a favorable point for discharge — probably there is no other so good in the whole harbor.

Under your direction, Mr. Howard A. Carson, C.E., has devised two plans of works for collecting the sewage of the various towns and cities that should unite in the common system, and for its discharge in a crude state at this point. One provides for the retention of the sewage in reservoirs on the southerly point of Deer Island during flood tide, that it may be discharged during ebb tide; the other, by the omission of the reservoirs, involves a continuous discharge.

The experience gained by the discharge of the sewage of Boston into the ebb-tide current off the easterly end of Moon Island shows that sewage thus discharged into the still stronger current at the Beacon would be quickly dispersed and lost to the senses. There can be no reasonable objection to this mode of disposal.

The float experiments that have been made at this point recently, when considered in connection with the fact that the sewage discharged at Moon Island disappears in a run of about two miles, point strongly to the conclusion that the discharge need not be confined to the ebb tide, but may be made continuously. If this should prove true, — and I have little doubt that it will, — consid-

erable saving in first cost and in cost of operating can be effected, as is shown by comparison of the estimates.

The two plans are alike except in the capacity of the discharge sewers or pipes, and that one provides for a reservoir and the other does not. Therefore, should trouble arise from the continuous discharge, the remedy could be readily applied. Both plans provide means for depositing and retaining the heavier matter of the sewage, that it may not be discharged into the channel.

After careful consideration of the experiments that have been made and the data that have been collected, I would recommend that the sewage of the Mystic Valley and of the cities of Cambridge, Charlestown and Somerville be collected into one system of sewers, and discharged continuously at or near Deer Island Beacon.

I have been over the ground to study the location of the main sewers, and have reviewed the estimates of cost with care. I believe the location to be well selected, requiring only such minor changes as the closer survey and study which precede actual construction usually suggest, and also believe that the estimates are liberal, and will fully cover the cost of construction under intelligent management.

In conclusion, I am of opinion that the schemes recommended by the committee for the disposal of the sewage of the Mystic and lower Charles valleys are well devised, and that they will relieve these valleys from the danger threatened by the present method of discharge; and I can suggest no other practicable scheme that would not involve a much greater cost either of construction or of operating.

Respectfully submitted,

JOS. P. DAVIS,
Consulting Engineer.

NEW YORK, DEC. 17, 1888.

ENGINEER'S REPORT.

By Howard A. Carson, C. E.

Boston, Nov. 20, 1888.

Hiram F. Mills, Esq., *Chairman of Committee on Water Supply and Sewerage, Massachusetts State Board of Health.*

Dear Sir: — In your letter of Oct. 3, 1887, I was asked to "take into consideration the whole subject of the disposal of the sewage of the Mystic valley, in its crude condition, into tide water," where it would cause no nuisance; to decide on the best point for discharge; to determine the best route for bringing the sewage to this point, and to make such plans as might be necessary to enable me to make reliable estimates of the cost of this scheme of disposal. At a later date you gave an estimate of the population in 1930 of various towns and cities in and near the valley, and directed sewers to be designed of sizes and inclinations sufficient to carry thirty-five cubic feet per head per day for this estimated population for Somerville and Cambridge, and thirty cubic feet per head per day for all other cities and towns included in the scheme.

The following table gives the estimate of population and the corresponding quantities of sewage alluded to above: —

TOWNS AND CITIES.	Cubic Feet per Head per Day.	Estimated Population, 1890.	Estimated Population, 1930.	Cubic Feet per Second, 1930.
Woburn,	30	13,300	23,200	8.1
Stoneham,	30	6,700	11,300	3.9
Winchester,	30	5,000	10,300	3.6
Arlington,	30	5,000	9,500	3.3
Belmont,	30	1,900	3,000	1.0
Somerville,	35	34,800	76,000	30.8
Cambridge,	35	67,000	126,000	51.0
Medford,	30	10,100	18,900	6.6
Melrose,	30	7,000	13,500	4.7
Malden,	30	17,900	37,000	12.8
Everett,	30	7,200	16,700	5.8
Chelsea,	30	27,800	49,100	17.0
East Boston,	30	32,100	50,200	17.4
Winthrop,	30	1,900	4,200	1.5
Charlestown,	30	40,900	64,100	22.3
Total,	–	278,600	513,000	189.8

Careful consideration has been given to various schemes of sewerage, some of which provide outlet sewers for all the towns and cities mentioned in the foregoing table, and others of which provide for a part only. The valuable data collected by previous commissions, particularly that of 1885, were made use of, and were added to by new surveys, soundings and observations of tidal currents. It will be noticed that numerous sewer routes recommended by the last commission are here again recommended.

The results of my studies as they progressed have been given both to the committee and to your chief engineer. I herewith respectfully submit a more extended report of the scheme designated the North Metropolitan sewerage system, and shown on map No. 1, which provides for all the towns and cities named in the table. Estimates and explanations of other plans, including one for an intercepting sewer for the lower Charles River valley, are also appended.

Much time and study were devoted to finding a suitable locality for the outlet of the North Metropolitan sewers. The safe disposal of the volume of sewage indicated in the foregoing table requires that this outlet be remote from densely populated districts. The flow should be, if practicable, directly into an ocean current of such force and direction that the sewage will be speedily diffused at a distance from inhabited shores. No locality was found where these conditions could be so perfectly and economically fulfilled as that of Deer Island. Revere Beach north of Grover's Cliff is the sea-coast nearest to what may be called the centre of gravity of population of the towns under consideration, but it is improbable that any suitable current exists there, and, moreover, it is thought that its growing importance as a crowded summer resort excludes it from consideration as a possible place of discharge. Our observations of tidal currents made at Shirley Gut gave less satisfactory results than those made by previous observers. They appeared to show that sewage there discharged would make deposits in the immediate vicinity, and create a nuisance. The float experiments were made under the direction of Mr. Laurence Bradford, who has had much experience of a kind to fit him for such work. One hundred and one floats were set off altogether — charts showing the paths of which were sent to you. Seventy-five of these were sent from near Deer Island Beacon, about two thousand feet south of the southerly end of the island; and eighteen from near Great Faun Beacon, three-fourths of a mile east of the island. Some of the relative advantages and disadvantages of the Great Faun Beacon and Deer Island Beacon as places for sewer outlets may be stated. Great

Faun Beacon is more than a mile nearer the ocean, measuring in the direction of the channel, and may, in fact, be considered as in the ocean. The currents near Great Faun Beacon at different stages of the tides are uncertain, sometimes moving rapidly seaward, and at other times vacillating about to the eastward of the beacon. Should the outlet be in this vicinity, it is probable that some of the heavier particles in the sewage will be deposited near by, and that a few light floating objects will be driven at times to different neighboring shores. Deer Island Beacon, though not so near the ocean, is a mile from any dwelling, is nearly four miles from South Boston, and is more than five miles from Boston proper. One hour before high water the current at this point is established in a seaward direction. Sewage discharged between one hour before and four hours after high water would move with a fair current to sea, and none would return with the following flood tide. Sewage discharged at other stages of the tide would move some distance into the harbor, but, as explained later, would not get near any inhabited shore. Either of these localities is an excellent place for discharge. The relative advantages and disadvantages of the two places, as far as currents and position together are concerned, are nearly balanced; but, were the cost the same, I should somewhat prefer the Great Faun outlet. It may be added that any attainable point on a curved line joining the two points mentioned and the intermediate one of the end of Little Faun bar would also be excellent. The cost of construction would be considerably less near Deer Island Beacon, and that place was therefore adopted.

The Board of Engineers of the United States Army have long thought of placing fortifications on Deer Island. The area required for such use is officially stated by the Board to be "the portion south of an arc of a circle described with a radius of fifteen hundred feet from the extreme south-eastern point of the island as a centre; also space for certain batteries on the north-eastern shore of the island, which would not be interfered with by the projected sewer system." Part of the first-described area would, were it not thus possibly excluded, afford a convenient site for a storage reservoir, should one ever be needed. Ample space remains, however, in the northerly part of the low plain at that end of the island, and a space many times what can ever be required is found still farther north. The best site for a pumping station is entirely outside of the proposed military reservation.

It seems probable that a reservoir will not be needed for years, if at all. Deer Island is about two and one-half miles nearer the ocean, measured in the direction of the current, than the outlet of

Moon Island reservoir. It is about three miles nearer than Castle Island, which was considered by several engineers and commissioners as a possible place of outlet for the Boston intercepting sewers. It is four and one-half miles nearer the ocean than the place recommended by Messrs. Clarke, Davis and Hering and the commission of 1885 for the outlet of the East Boston sewers. These gentlemen thought no ill result would follow from discharging the East Boston sewage continuously into the harbor at the place mentioned. The most westerly point reached by any float from Deer Island Beacon is nearly a mile east from this place. One float, however, started at low water, went up the channel towards Breed's Island, and grounded on the eastern end of Noddle Island. Floats started during flood tide, that went as far west as Castle Island, were about three hours in reaching that point. None of our floats went farther west than the vicinity of Castle Island, and long before reaching that point, sewage from the proposed outlet would disappear. An experiment with sewage from Moon Island reservoir, made last September, confirms this view. It may sometimes happen that grease balls or other light objects will get ashore at points farther up the harbor. Our experiments and observations thus appear to demonstrate that no nuisance would be caused for many years, if ever, by discharging continuously near Deer Island Beacon. The saving in interest alone would within twenty years pay the cost of a reservoir and additional outlet pipes. The cost of pumping and other items of expense will also be lessened by dispensing with a reservoir and discharging continuously. Even if a reservoir were needed, it would cost no more to build at a later time; and therefore, in any event, such building should be postponed until the effect of discharging the sewage continuously is clearly seen.

If suitable arrangements can be made to prevent deposits, the considerable storage capacity of the sewer on Deer Island and above can be made use of to avoid discharging at low stages of the tide.

A suitable outlet sewer can be constructed without serious difficulty. A pier from the main land to the proposed outlet near the beacon would be exposed to heavy waves in the winter season, and its protection from their destructive power would be very costly. No pier, however, is necessary or desirable. The outlet sewer can be placed entirely below the bed of the sea on its proposed line near the bar. Thus placed it will be entirely safe from the action of sea-waves. If a reservoir is dispensed with, as is here recommended, two lines of cast-iron pipe, four feet in diameter, will furnish a suitable outlet for years, and three lines will

suffice for the estimated population of 1930. In laying this outlet sewer, dredging will secure the necessary depth, and the pipes can then be laid with the help of divers. The art of laying iron pipe under water is well advanced, having been extensively practised in various parts of the world. Some miles have been laid in this country. In the estimates attached to this report, very ample allowance has been made for the cost of outlet pipes.

A heavy masonry sewer, with a much greater discharging capacity than the three lines of pipe, could be built for the price allowed for them. The price would cover the cost of a coffer-dam, and the operations required to place the sewer entirely below the surface of the bar. Any sewer here, however, will be subjected to a considerable bursting pressure, and the strength of masonry to resist such strains is uncertain. A wooden sewer, six feet square inside, would have greater discharging capacity than the three pipes. Such a sewer could be so framed as to be amply strong against both bursting and collapsing pressures, and could be laid entirely below low water without the aid of a coffer-dam. Its cost when laid would probably be less than that allowed for two pipes. It is thought that it would not be attacked by the *teredo* or *limnoria*. But this question and others connected with its use require further investigation, and it has been considered prudent in this report and estimate to adopt cast-iron pipes.

The question of pumping stations and that of route of main sewer are to some extent interdependent. If the cost of construction for a given size was everywhere the same, under plain, hill, valley or sea, then the most economical route for a main sewer with outlet at Deer Island, and for the drainage of the towns under consideration, would run in a nearly straight line from Deer Island to near the centre of East Boston, thence to the middle of the Mystic River near Medford bridge, and thence to West Medford. Physical obstacles, however, especially the sea and rivers, compel some deviation. The distance from West Medford to Deer Island by the line as designed is about eleven and one-half miles. By the ideal line alluded to above, the distance would be lessened more than one mile.

Starting in West Medford low enough to provide fair drainage for the adjacent territory, and continuing on the route as planned, with suitable sizes and least permissible inclinations, the bottom of the sewer on Deer Island would be more than twenty-four feet below low water, or thirty-eight feet below the surface of the low plain at the south end of the island. The last five miles of this sewer would require a trench of thirty-five feet average depth. On account of its depth and its distance below the water table, its

excavation would be difficult and exceedingly expensive. In order to discharge into the sea, elevation by pumping would be necessary. If discharged continuously at all stages of the tide, this elevation would vary from say twenty-four to thirty-four feet, depending on size of outlet and stage of tide. If pumped into a reservoir to be discharged at the upper stages of the tide, the lift would depend on the design, but would probably be greater. If, in place of making this lift by pumping on Deer Island, it should be made in the westerly part of Breed's Island, as contemplated by previous commissions, and if the outfall sewer should be made of masonry, then the five miles of deep trench alluded to above would be avoided, and we should have five miles of sewer mostly above the present surface of the ground, and requiring embankment. Wide stretches of marsh would have to be crossed, and here the necessary foundations would be exceedingly costly. Numerous steam and common roads would have to be passed under by inverted siphons. This high-level sewer might prove as costly as the deep one first alluded to. This sewer, also, would be too high for the sewage of Winthrop and Breed's Island.

By carrying the sewage from the pumping station at Breed's Island in force-mains of cast-iron pipe, the heavy embankments and extra siphons could be avoided. The cost, however, would still be excessive. An outfall sewer of masonry, nine feet in diameter, with a fall of one and three-fourths feet per mile, would have the requisite carrying capacity. It would require four pipes each four feet in diameter, and with four times as much fall, to do the same work. A masonry sewer, nine feet in diameter, placed in excavation twenty feet deep, and of considerable difficulty, would cost only half as much as the four pipes laid at depths of ordinary water pipes. The work of pumping would be only one-fourth as much for this masonry sewer as for the pipes. The iron force-mains would not be more available for the sewage of Winthrop and Breed's Island than the high-level sewer in embankment already referred to. It thus appears that, if all the pumping takes place at Deer Island, the main sewer is very costly on account of depth; and, if it all takes place at Breed's Island or its vicinity, the sewer is also very costly, and loses part of its usefulness by being too high.

Study of the profile makes it clear that, by having two pumping stations, one at Deer Island and one four or five miles back on the sewer line, we can divide the lift and so place the sewer as to avoid excessive depth on the one hand and costly embankment on the other. This division is accordingly adopted, and the second of these stations is placed at East Boston, the line from which has

less length of marsh than the Breed's Island line above referred to. An upward step of about sixteen feet takes place at this station, and this step, of course, lessens by that amount the depth of excavation on the sewer line thence to Deer Island. The sewer is still deep enough to pass under all steam and other roads without sags or siphons, and to rest on hard bottom through most of the marshes. It is also low enough to receive the sewage of Winthrop, the inhabited part of Breed's Island, and part of East Boston east of the pumping station.

It is plain that this increase of pumping stations does not increase the total work of pumping, measured in foot-pounds or otherwise. The comparatively low lift at each place will enable centrifugal pumps to be employed. In the matter of weight, space, liability to accident, and especially in cost of pumps and cost of foundations and buildings, the advantages are very greatly in favor of centrifugal as compared with reciprocating pumps. The former, also, from the absence of valves, are better adapted to pumping sewage. A few examples of low-lift centrifugal pumps have shown a fuel economy approximating to that of many of the high-lift pumping engines of the country; but in general the former will require a much greater consumption of fuel for a given amount of work than the best types of high-lift reciprocating pumps. It will also require care and skill to so proportion the former as to permit the necessary variation in delivery. Two small pumping stations instead of one large one may also somewhat increase the cost of maintenance, by requiring more employees.

Taking into account interest and depreciation on plant and buildings, as well as consumption of fuel and all other items of expense, it is found, in the case under consideration, that two low-lift stations with centrifugal pumps are as economical as one high-lift station with reciprocating pumps. It has already been shown that the cost of sewers in the former case is very much less.

The same reasoning which led to placing pumping stations at East Boston and Deer Island also led to placing one in Charlestown, for lifting the sewage of that city, Cambridge and Somerville. If this sewage should be carried without lift in a sewer falling continuously on the route to the East Boston pumping station, it would involve making four miles of trench excavation fifteen feet deeper, and it would also involve pumping one-half of all the sewage of the system fifteen feet higher than according to the present design.

MAIN SEWER OF THE NORTH METROPOLITAN SEWERAGE SYSTEM.

Ten years ago the city of Boston built the so-called Mystic Valley Sewer from Woburn Centre to the lower Mystic Lake. Its route lies near the Woburn Branch and the main line of the Boston and Lowell Railroad. It is proposed to incorporate into the North Metropolitan System so much of this sewer as lies between the Woburn and Winchester town line and a point 300 feet above its outlet. At the Woburn town line this sewer consists of a 15 inch pipe with the invert about 67 feet above mean low water of the sea. It continues on the east side of the Woburn Branch Railroad, falling at a rate of not far from 1 in 100 to a point near Moseley's tannery. It then descends at a rate of 1 in 10 for a distance of 234 feet, and enters a man-hole of the brick portion of the Mystic Valley Sewer. This sewer is 26 by 28 inches in diameter, and has an inclination of 1 in 1,000. It has a carrying capacity of about 5,600,000 gallons per day. At the upper end of this brick sewer it is designed to take in what will be called the Cummingsville branch, and also a branch from Stoneham. The length of the 15 inch pipe sewer is about 2,800 feet and that of the brick sewer about 11,500 feet. The estimated value of that portion of the Mystic Valley Sewer incorporated into this system is $68,000. About 300 feet from its present outlet into Mystic Lake it will be discharged into a new sewer of larger diameter.

The proposed new sewer is 3 feet 2 inches in diameter, and has an inclination of 1 in 2,000. Its location is on the route selected by the commission of 1885, in private land to the Boston and Lowell Railroad, and thence partly in the railroad location and partly in private land just east of it to Prescott Street in West Medford. As located, the line southerly from High Street runs close between the railroad and some private buildings. This can be avoided by locating about 1,000 feet of this section in Warren and Canal streets. This change would lessen the depth of excavation and lessen the distance in private land, but would add slightly to the length of the sewer.

At Prescott Street the Alewife Brook branch is taken in, and the main sewer is enlarged to 4 feet 4 inches in diameter. The bottom of the invert of the sewer is here 8 feet above mean low water of Boston harbor. The route of the sewer continues through the whole length of Prescott Street and then through marsh land by a nearly straight line to High Street, a little east of Hillside Avenue, and continues in High Street to Central Square. The bottom of the invert of the sewer is here 5 feet

above low water. At this point the sewer is enlarged to 4 feet 6 inches in diameter. The route of the main then turns into Riverside Avenue and passes under the Medford Branch Railroad. The sewer continues in the avenue to the village of Wellington. The line is there slightly deviated to avoid the hill, and is continued through Third Street.

Near Middlesex Avenue the sewer is enlarged to 5 feet diameter, and receives by a 2 foot branch at Cradock Avenue the sewage from the village of Edgeworth. Continuing in nearly a prolongation of Third Street, the sewer passes under the Boston and Maine Railroad with its invert at the level of low water. The inclination of the *gradient* of the sewer between Middlesex Avenue and the Malden River is, when flowing full, 1 in 2,500. The invert of this section has an inclination considerably greater.

As designed, the sewer under the Malden River will consist of two lines of cast-iron pipe, 2 feet 6 inches in diameter, laid under the bed of the stream. This will cause a depression in the sewer, as shown on the profile, of about 6 feet. This siphon is of small diameter, in order to ensure sufficient velocity to prevent deposits of sand. As a further precaution, it is designed to place two sumps or sand-catchers on the west side of the stream, and means of isolating each of these for cleaning out. An overflow and other suitable appliances are designed and estimated, to enable the pipes under the river to be pumped out and examined, and, if necessary, cleaned at any time.

After passing the Malden River, the sewer continues across the marsh to a point west of and near the Saugus Branch Railroad, about 800 feet south of the West Everett station. At this point the Melrose branch enters, and the sewer is enlarged to 5 feet 6 inches in diameter. The soundings across the Malden River marsh indicate fine sand. This, at considerable depths and in close proximity to clay, is sometimes difficult and costly to excavate.

The sewer, after junction with the Melrose branch, turns to the right and continues in the marsh and projected streets nearly parallel to the branch railroad, turns to the left into West Street and passes under the railroad, with the invert 5¼ feet below low water, then passes through West Street to Main, and thence through private land and across Broadway to Paris Street. At Broadway the main sewer receives the Cambridge branch, and is enlarged to 8 feet 2 inches in diameter, and has its invert 6 feet 3 inches below low water. The main will also probably receive at Broadway an important local Everett sewer. The main sewer,

with a fall of 1 in 3,000, proceeds through Paris Street, across the marsh to Second Street, and follows the latter into Chelsea.

For about three-quarters of a mile in this vicinity the sewer will be surrounded by peat and mud, and will require a reinforced cross-section and a pile foundation. The mud will be easy to excavate, but the foundation and backing will necessarily be expensive. For most of this distance the mud extends only a short depth below the sewer, and short piles will suffice. For a short distance, however, near Cypress Street, the pocket of mud has a depth of more than 25 feet below the sewer.

At the junction of Spruce Street with Second Street the Spruce Street sewer will be intercepted, and the main sewer is there enlarged to 8 feet 5 inches in diameter. Its crown is about 2 feet below the Spruce Street sewer, and its invert is 8 feet 6 inches below low water. The main continues in Second Street, the surface of which begins to ascend rapidly at Arlington Street. At Broadway the depth of excavation is 44 feet. The sewer crosses Broadway Square, continues in Winnisimmet Street to Williams Street, which it follows to Marginal Street and through this to Eastern Avenue. At Pearl Street on Williams the depth of excavation, which decreases after passing Broadway, is 29 feet. The necessary depth of excavation in Chelsea, although great, has often been equalled and sometimes exceeded in constructing intercepting sewers in other cities. It is not unlikely that, when this section is built, a large volume of water will be met and require a considerable pumping plant. It is designed to retain most of the present outlets of sewers in Chelsea for storm overflows, and to provide them, where necessary, with efficient tide-gates.

At Eastern Avenue the Chelsea branch is received. At this point the sewer turns to the right and proceeds to Chelsea River. This is passed under by two lines of 4 feet cast-iron pipe. Like provisions for preventing deposits are here made, but more extensive than those provided at Malden River.

The siphon under Chelsea River is located between the highway and railroad bridges. The sewer turns to the left on reaching Addison Street, and receives the main East Boston branch. Enlarged to 9 feet in diameter, it passes under the Boston and Albany Railroad, and reaches the proposed East Boston pumping station with its invert $12\frac{8}{10}$ feet below low water.

The triangular space enclosed by the two railroads and Chelsea River is at present unoccupied. The ground is of a stable character, there is ample frontage on a navigable river, and the surroundings are such as to make a pumping station unobjec-

tionable. As designed and estimated, the pumping plant will consist at first of four centrifugal pumps and two compound condensing engines, capable of lifting 185 cubic feet per second 20 feet. The difference in level between the incoming and outfall sewers is $15\frac{2}{10}$ feet. This pumping station may receive in the future a low-level sewer, draining a low district in Breed's Island and one in East Boston proper. In connection with this station, sumps and settling tanks are designed and estimated, by which sand may be separated from the sewage and deposited in scows or otherwise, for waste, or for filling the neighboring low grounds.

The outfall sewer on leaving the pumping station has its invert $3\frac{1}{10}$ feet above low water. It passes through Addison Street to Saratoga Street, and through this to Butler Avenue on Breed's Island. Its invert at the Boston, Revere Beach and Lynn Railroad is about 2 feet above low water. It continues through Butler Avenue and Faxon Street to Belle Isle Inlet. Some mud will be met in the excavation between the pumping station and Belle Isle Inlet, but none that extends below the bottom of the sewer. This outfall sewer is low enough to receive the sewage of part of East Boston east of the pumping station and of all the inhabited part of Breed's Island. Belle Isle Inlet is passed under by two lines of 4 feet cast-iron pipe. Provisions similar to those heretofore described are made here for catching sand and for examination and cleaning out.

In Winthrop the line runs between Main Street and the Boston, Winthrop and Shore Railroad not far from the latter, to the junction of Main and Revere streets. The sewer then proceeds in Main Street and its projection across the marsh and enters Shirley Street. A section of the sewer 1,800 feet long in the marsh will be surrounded by mud, which extends 4 feet below the sewer at the deepest place. This section is designed to have a masonry reinforcement, and the mud under it removed and concrete or gravel substituted therefor. The sewer continues in Shirley Street, reaching Shirley Gut with its invert $5\frac{7}{10}$ feet below low water. The sewer as planned is low enough to afford a good outlet for the Winthrop sewers. Shirley Gut is passed under with two lines of 4 feet pipe. A rapid current always flows here, except for a short time at high and low water. Owing to this fact, and to the depth of water, the cost per foot of crossing will be greater than at the other siphons. Provisions for inspecting and cleaning are allowed for.

The sewer line on Deer Island, as located, runs from the narrowest part of the Gut by the front of the hospital and the main building, and continues in the road on the western side of the

island to the proposed pumping station. This is located north of the proposed military reservation on the plain at the southerly end of the island. The sewer arrives at this point with its invert nearly 8 feet below low water. The sewer has a uniform diameter of 9 feet from East Boston to Deer Island between the two pumping stations.

The Deer Island pumping station in size and equipment will not differ greatly from that at East Boston. Its foundation will be of considerably less depth, and its cost in that respect will be somewhat less. The height of pumping at this station will vary, depending on the stage of the tide and several other factors. With a delivery at half tide corresponding to 112 gallons per head per day of the estimated population in the year 1900, through the outfall sewer and two lines of 4 feet pipe, the lift will be about 11 feet. An outfall sewer 6 feet wide and of varying height extends southward from the pumping station a distance of 1,000 feet. Its upper part is considerably below the present surface. At its lower end it connects with two lines of 4 feet cast-iron outlet pipe which extend to near the Deer Island Beacon, about 2,000 feet from the shore. This pipe is designed to be laid below the bed of the harbor, at such a depth that its top will be from one to three feet below low water. In this position it will be entirely safe from the action of storms. The outer end of the pipe is designed to turn up, and have its bottom 6 inches above low water. Massive masonry similar to that in the present beacon will be necessary to protect the end from the heavy easterly gales. The outer end of Deer Island bar is under the control of the Light-house Board of the United States government, and it is designed to place a light-house there. The proposed location for the sewer outlet is just west of the bar.

Cummingsville Branch.

The sewage of Cummingsville and some other parts of Woburn cannot economically reach the present Mystic Valley Sewer without going through a portion of the town of Winchester. The Cummingsville branch provides an outlet in Woburn for such sewage. This branch sewer consists of a 15 inch pipe, with a uniform fall of 1 in 800. It begins at the town line on the Horn Pond Ice Railroad, with its invert 34½ feet above low water. It follows this road and the westerly side of the Woburn Branch Railroad. Near Moseley's tannery it crosses the railroad and enters the man-hole at the upper end of the brick sewer. Its invert is here $29\frac{7}{10}$ feet above datum, or a little more than 5 feet above the bottom of the brick sewer.

Stoneham Branch.

This is built almost wholly in private lands. Its upper end begins near Railroad Street at the line between Stoneham and Woburn. It consists at first of a 15 inch pipe, with its invert $47\frac{7}{10}$ feet above datum, and its inclination 1 in 160. The line runs near and mostly north of the Stoneham Branch Railroad for 2,000 feet. It crosses the railroad between Hill and Maple streets, and is enlarged near the latter to 1 foot 8 inches in diameter, with an inclination of 1 in 1,000. It crosses to the west bank of the Abbajona River about 400 feet south of the railroad. At Washington Street the diameter is increased to 2 feet. The Boston and Lowell Railroad is crossed about 800 feet north of Cross Street. The sewer continues nearly parallel to the river, and enters the main brick sewer near its upper end. This branch takes nearly all of the Stoneham sewage, and serves also parts of Woburn and Winchester.

Alewife Brook Branch.

This branch lies mostly in private land on the easterly bank of the brook. It is designed to carry the sewage of Belmont, Arlington, and parts of Cambridge, Somerville and Medford. It begins at Concord Avenue, where it intercepts a Cambridge sewer. Its diameter here is 1 foot 6 inches, its invert is $6\frac{7}{10}$ feet above datum, and its inclination is 1 in 1,200. At Spruce Street it receives another Cambridge sewer, and also the Belmont branch, and its diameter is increased to 2 feet 2 inches, and its inclination flattened to 1 in 1,500. A third Cambridge sewer enters at North Avenue. Branches for Arlington are provided as follows: a 12 inch pipe north of the Middlesex Central Railroad, a 15 inch pipe at Charlestown Street and a 12 inch pipe near Decatur Street. These branches are merely extended across the brook to the Arlington side. The Alewife Brook sewer is successively enlarged, becoming 3 feet 2 inches in diameter at Broadway in Somerville. A branch 10 inches in diameter is placed opposite Jerome Street to receive the sewage from a low portion of West Medford.

Near the pumping station of the Mystic Water Works it is proposed to provide a small pumping plant to lift the sewage into a higher sewer, which will discharge into the main sewer at Prescott Street, West Medford. The upper and lower sewers are $14\frac{6}{10}$ feet apart vertically at the pumping station. As the work of pumping sewage at this station will probably not exceed thirty horse-power for some years, and will average much less than this,

it is possible that steam and attendance can be furnished from the water-works station. For this and other reasons the station is here located. Considering the cost of construction alone, it would be cheaper to place the sewage pumping station about 1,500 feet farther south. The upper sewer from the pumping station is 3 feet in diameter, except at the Mystic River siphon, which is composed of two lines of 20 inch iron pipes. The general inclination is 1 in 1,000. A 10 inch branch is carried in Boston Avenue to the Medford town line.

The Belmont branch begins near the town line between Cambridge and Belmont, and for 2,500 feet follows along the southerly side of the Fitchburg Railroad. It then crosses the latter, and, following the southerly side of the Central Massachusetts Railroad, enters the Alewife Brook sewer near Spruce Street. It consists of a 15 inch pipe, starting at grade $8\frac{3}{10}$, and having a uniform inclination of 1 in 1,000 throughout its length.

Melrose Branch.

The Melrose branch, so called, is designed to carry the sewage of Melrose and also that from parts of Stoneham, Malden and Everett. It begins in Wyoming Avenue, at the town line between Stoneham and Melrose, with a 10 inch pipe $47\frac{1}{10}$ feet above datum, and with an inclination of 1 in 500. At Waverley Place, Melrose, the diameter is increased to 1 foot 10 inches, and the inclination flattened to 1 in 1,000. The sewer passes through Waverley Place, and a proposed extension of it, to Winter Street, Malden, where its diameter is increased to 2 feet. The sewer proceeds through Linden Avenue, Pleasant and Middlesex streets to Charles Street. In Pleasant and Middlesex streets the sewer has a rapid fall which permits the size to be somewhat diminished. After passing under the Saugus Branch Railroad the diameter is increased to 3 feet 4 inches, and the fall is made 1 in 2,500. The invert is here $1\frac{1}{4}$ feet below low water. The very flat inclination is made to give an outlet for sewage from the low parts of Linden. This flat section of sewer may require frequent flushing. Water for this purpose can be had from the Malden River and from a brook at Linden. The route of the sewer from Charles Street is through private land, Green and Tremont streets, to the main sewer south of the West Everett station.

Cambridge Branch.

For convenience, this name is given to the central intercepting sewer designed to carry most of the sewage of Cambridge, Somerville and Charlestown. It begins near the junction of Mt. Auburn

and Lowell streets, Cambridge, 2 feet in diameter, 6 feet above low water, and with an inclination of 1 in 1,500. Its route lies at first in Mt. Auburn, Eliot, South, Holyoke, Mill, DeWolf streets, and across private land to the junction of Western Avenue and Blackstone Street. At this point the invert is about level with low water. Numerous sewers are intercepted, and the diameter is successively increased, being here 3 feet 7 inches. Connections for intercepting the Sparks and Willard streets sewers must be made at considerable distances back from Mt. Auburn Street, in order to get points where they are sufficiently above the main intercepting sewer. The inclination of 1 in 1,500 is maintained from Lowell Street for a distance of 1½ miles. Proceeding through Blackstone Street, and a short distance in River Street, the sewer crosses about 1,500 feet of marsh land to the junction of Granite and Magazine streets. The excavation on this section will be through mud, and pile foundations will be required. At Pleasant Street a sewer is intercepted, and the diameter of the intercepting sewer is increased in size.

From Pearl Street the sewer proceeds with a diameter of 4 feet 2 inches and a slope of 1 in 2,500, through private land, Waverley, Albany and Portland streets to Binney Street, where the system of sewers having outlet in that street can be intercepted. The invert of the intercepting sewer is here 6$\frac{9}{10}$ feet below low water, the diameter is 5 feet 4 inches, and the inclination is 1 in 3,000. The route of the sewer then lies in Portland, Warren and Medford streets. The large sewer in Bridge Street can be tapped near its outlet by a pipe, which will discharge into the intercepting sewer at the junction of the last-named streets. The invert of the intercepting sewer where it passes under the Fitchburg Railroad at Medford Street, Somerville, is about 8 feet below low water. The depth of excavation is here 25 feet, in clay and gravel.

About 200 feet beyond this point the sewer turns to the right and crosses a narrow lot to Somerville Avenue, where a large sewer will be intercepted. Here the intercepting sewer becomes 6 feet in diameter. The route of the sewer then lies in Poplar Street and across the Boston and Lowell Railroad into and across the grounds of the McLean Asylum to Waverley Street. The depth of excavation near the Boston and Lowell Railroad is 33 feet. At Waverley Street a sewer which now discharges through a ditch into the open marsh will be intercepted. The route of the sewer lies next in Washington Street in Somerville, and Cambridge Street in Charlestown, where some rock excavation is met with. The trench, if made in open cut, will be 29 feet deep under the Boston and

Maine Railroad tracks. Test shafts may show that it is better to tunnel at this place.

The main turns to the left at Sullivan Square, and at Rutherford Avenue and Main Street the Charlestown branches are received. At Rutherford Avenue the diameter is increased to 6 feet 8 inches. Entering Alford Street it continues to Arlington Avenue, where the Somerville branch enters. Three hundred feet farther on the sewer turns to the left and enters the site for the proposed pumping station. The proposed site is an unoccupied piece of land just above Malden bridge on the Mystic River. Here the invert is 11 feet 7 inches below low water. This site has ample water front, firm ground, suitable surroundings, and other requisites for a sewage pumping station. The pumping station at this place is similar to that at East Boston, but has little more than half its capacity. Included in the design and estimate are provisions for removing sand. The lift at this station, reckoned from corresponding points in the incoming and outgoing sewers, is $14\frac{4}{10}$ feet.

It is designed to retain for storm overflows most of the present outlets of sewers in Cambridge, Charlestown and Somerville, and provide them, where necessary, with efficient tide gates.

The siphon under Mystic River consists of two lines of 40 inch cast-iron pipe, with suitable provision for inspecting and cleaning. At the north end of the pile bridge, the iron pipes enter a chamber from which proceeds a masonry sewer 6 feet in diameter, with invert at low-water level, and with a fall of 1 in 1,400. The route of this sewer lies in Alford Street and Broadway, Everett, to Paris Street, where the main trunk sewer is entered.

Charlestown Branches.

The principal Charlestown branch begins in Chelsea Street at Medford Street, where the outlet of a considerable system of sewers is intercepted. The intercepting sewer has here a diameter of $1\frac{1}{2}$ feet, an elevation of $3\frac{1}{2}$ feet above low water, and an inclination of 1 in 750. The route of the sewer lies in Chelsea Street to near Vine Street, where it enters and passes through the navy yard grounds, with a diameter of 2 feet 2 inches, and a fall of 1 in 1,000. The route through the navy yard avoids the deep excavation that would be encountered if it was continued on Chelsea Street. At Water Street the diameter becomes 2 feet 6 inches, and the inclination is 1 in 1,500. The sewer passes through Water and Front streets. Both sides of the latter are occupied entirely with freight houses. As this street is constantly crowded with teams during the day, skill and care will be necessary in building this section to prevent injury to business.

On some parts of this route deep excavation will be required in close proximity to heavy buildings. The sewer is continued through Austin and Chapman streets to and through Rutherford Avenue to the so-called Cambridge branch sewer. Numerous city sewers are intercepted on the route described, and the intercepting sewer becomes 2 feet 10 inches in diameter in Rutherford Avenue. Another Charlestown branch of 15 inch pipe, with an inclination of 1 in 75, intercepts a system of sewers having an outlet at Beach Street. This branch has its upper end at the junction of Main and Beach streets. It traverses part of Main Street, and discharges into the Cambridge branch at Alford Street.

Somerville Branch.

The Somerville branch is designed to take sewage from a part of Medford lying south of Mystic River, and from a northerly portion of Somerville. It begins in Mystic Avenue at the Somerville and Medford town line, with a diameter of 18 inches and an inclination of 1 in 1,000. At Winthrop Avenue an important sewer is intercepted, and the diameter is increased to 2 feet 6 inches. The sewer leaves Mystic Avenue at Austin Street, and, passing through private land and under the Boston and Maine Railroad, enters and goes through Arlington Avenue to the Cambridge main. In Arlington Avenue the diameter is increased to 2 feet 8 inches.

East Boston Branches.

An intercepting branch sewer is designed to start at Sumner Street on New Street, at grade $4\frac{8}{10}$ feet, and proceed through New, Maverick and Border streets to Central Square. Another branch starts at Meridian Street on Condor Street, at grade 14, and follows this and Border Street to Central Square, where it joins the branch just described. These two branches are designed to intercept all the sewers now discharging on the westerly side of East Boston. The intercepting branches are of 12 inch pipe at their upper ends, and 15 inch at their lower, with inclinations varying from 1 in 250 to 1 in 500. Their sewage is carried through Central Square and Porter Street to Bremen Street, in a brick sewer with a diameter of 1 foot 7 inches, and an inclination of 1 in 400. The sewers now discharging at the south-east end of the island are designed to be intercepted by 12 and 15 inch pipes in Jeffries and Maverick streets, respectively, and a 12 inch pipe in Marginal and Orleans streets. The present sewer in Cottage Street will require to be tapped a short distance up hill from Marginal Street, and to be rebuilt just over the intercepting sewer.

The branch in Orleans Street joins the 15 inch pipe in Maverick Street. The latter proceeds with an inclination of 1 in 500 in Maverick and Bremen streets to Porter Street, where the westerly intercepting branch previously described is met. The sewage from these branches and from sewers now discharging on the east side is carried in Bremen, Prescott and Chelsea streets to near the Chelsea bridge, and there finds an outlet in the main sewer of the Metropolitan System. The Chelsea Street intercepting sewer is 3 feet 2 inches in diameter, and has a fall of 1 in 1,250. It has a carrying capacity of over 11,000,000 gallons per day. A branch at Eagle Square intercepts sewage discharging on the north side of the island.

The East Boston sewers receive storm water, for which relatively small provision is made in the intercepting sewers. For this reason, most of the old outlets are to be retained for storm overflows, and provided, where necessary, with efficient tide-gates.

Chelsea Branch.

This sewer, 2 feet 4 inches in diameter, in Eastern Avenue, Chelsea, is designed to intercept sewers now discharging on the easterly side of the city. It begins at Willowby Street, and has an outlet in the main at Marginal Street. It is so low that it can be extended to intercept the Prattville sewers when desirable, and it passes entirely under those to be intercepted on Eastern Avenue. On account of its passing through mud, where pile foundations will be required, the estimated cost is high.

In the appended estimate of costs no allowance has been made for a branch to Revere. Should it be desirable for the sewage of that town to enter this system, it is practicable to collect it north of Mill Creek, near the Eastern Railroad. A branch sewer from this locality can pass along the Eastern Railroad to Eastern Avenue, and through the latter, and enter the main sewer near the bridge to East Boston. This suggested Revere branch would take the place of the Chelsea branch described above. Its estimated cost is $86,000 more than that of the latter.

Estimates of Cost.

In the following estimates, sewers 18 inches or less in diameter are considered as made of stone-ware pipe. All larger sewers (except where otherwise stated) are brick, reinforced, where necessary, with rubble masonry or concrete. Brick sewers, 2 feet or less in diameter, are reckoned as having walls not less than 4 inches thick; those more than 2 feet and less than 6 feet in diameter as having walls at least 8 inches thick; and larger sewers as

having walls at least 12 inches thick. Man-holes and many other structures not mentioned are allowed for.

When extensive works like those under consideration are actually built, many considerable items of expense occur which cannot well be specifically estimated beforehand. Law suits, changes of plan due to new conditions, local physical obstacles more difficult to overcome than preliminary surveys indicate, are examples of such items. It is believed that the appended estimates are ample to include all such expenditures, and cover the entire cost of the works complete and ready for use.

The totals from the following estimate and from the estimates in the appendix are for convenience given here: —

First cost of the North Metropolitan Sewerage System (providing inlets for all towns in the table at the beginning of this report and with outlet at Deer Island) is .	$4,159,453
Cost of additions to the works up to A. D. 1930, . . .	224,400
Total cost of works up to A. D. 1930, ...	$4,383,853
Of which sum the intercepting sewers of Cambridge, Charlestown, East Boston and the east side of Chelsea amount to	$606,294

Estimates have also been made for three limited systems, including the towns of the Mystic valley, together with East Boston and Chelsea, but not including Charlestown and the larger part of Cambridge and Somerville, which estimates are given in the appendix, and result as follows: —

First cost of limited system discharging at Deer Island, .	$2,726,995
Additions to works up to A. D. 1930, ...	66,000
	$2,792,995
First cost of limited system centering at chemical precipitation station near Island End River, ...	$2,384,503
Additions to works up to A. D. 1930, ...	451,148
	$2,835,651
First cost of limited system discharging upon Saugus Marshes for filtration, and into Pines River, . . .	$2,654,626

Estimate of Cost of North Metropolitan Sewerage System.

SECTION.	Diameter of Sewer.	Average Depth of Excavation. Feet.	Length of Section. Feet.	Approximate Cost per Foot.	Total Cost.	Summary.	Remarks.
Main intercepting sewer:—							
From Mystic Lake to junction Prescott and Canal streets, in and near Boston and Lowell Railroad location,	3 ft. 2 in.,	22.4	6,000	$10 49	$62,960		Sand and gravel.
In Prescott Street, private land, and High Street to Central Square, Medford centre,	4 ft. 4 in.,	11.3	5,700	10 32	58,847		Sand and gravel, 400 lineal feet ledge, 1,300 lineal feet mud, requiring pile foundation.
In Riverside Avenue and Third Street to Middlesex Avenue,	4 ft. 6 in.,	16.1	8,500	11 23	95,470		Clay and gravel, 600 lineal feet mud, requiring pile foundation.
In Third Street and private land to Malden River,	5 ft.,	13.4	1,450	10 66	15,450		Sand and clay.
Sand-sump and overflow,	–	–	–	–	2,600		
Siphon under Malden River,	2 ft. 6 in.,	–	360*	–	9,000		Two lines cast-iron pipe.
In marsh land to junction with Melrose branch,	5 ft.,	13.9	1,950	10 80	21,057		Fine sand.
In Cross, West and Main streets, and private land to junction Broadway and Paris Street, Everett,	5 ft. 6 in.,	24.0	3,300	15 27	50,395		Clay.
In Paris Street, marsh and Second Street to Spruce Street, Chelsea,	8 ft. 2 in.,	21.4	5,700	35 63	203,072		Clay, sand and gravel, 2,700 lineal feet mud, requiring pile foundation.
In Second, Winnisimmet and Marginal streets to Chelsea River,	8 ft. 5 in.,	29.4	7,100	40 16	285,108		Clay, sand and gravel, 3,000 lineal feet mud.
Tide-gates and connections in Chelsea,	–	–	–	–	12,300		
Sand-sump, etc., in Chelsea at Chelsea River,	–	–	–	–	11,400		

Siphon under Chelsea River,	4 ft.,	–	830*	–	30,700		Two lines cast-iron pipe.
From Chelsea River to pumping station, East Boston,	9 ft.,	23.8	150	31 07	4,660		Clay and gravel.
Pumping station, machinery, sheds, wharf, etc.,	–	–	–	–	167,000		
From pumping station to Belle Isle Inlet, in Addison and Saratoga streets, Butler Avenue, Faxon Street and marsh,	9 ft.,	15.6	7,500	24 66	184,925		Clay, sand and gravel, 2,800 lineal feet mud.
Sand-sump and overflow, Belle Isle Inlet,	–	–	–	–	8,400		
Siphon under Belle Isle Inlet,	4 ft.,	–	1,300*	–	45,000		Two lines cast-iron pipe.
In private land, Main Street, marsh land, and Shirley Street to Shirley Gut,	9 ft.,	19.5	14,180	28 72	407,243		Clay, sand and gravel, 2,100 lineal feet mud, requiring pile foundation.
Sand-sump and overflow, Shirley Gut,	–	–	–	–	10,500		
Siphon under Shirley Gut,	4 ft.,	–	600*	–	31,000		Two lines cast-iron pipe.
On Deer Island to pumping station,	9 ft.,	25.2	4,100	28 33	116,172		Sand, gravel and clay.
Pumping station, wharf, machinery, dwellings, sheds, etc.,	–	–	–	–	164,000		
Outfall sewer from pumping station to gate-chamber,	8 ft.,	10.2	1,000	24 00	24,000		Sand, gravel and clay.
Gate-chamber and outfall pipe lines,	4 ft.,	–	4,000*	–	143,000		Two lines cast-iron pipe.
Land damages, Deer Island,	–	–	–	–	10,000		
Land damages, main intercepting sewer,	–	–	–	–	54,000		
						$2,228,259	
Cummingsville branch: —							
In Woburn Branch and Ice Railroad location,	15 in.,	19.8	3,800	4 48	$17,022		Wet sand and gravel.
Land damages,	–	–	–	–	1,300		
						18,322	
Stoneham branch: —							
In private land, East Woburn,	15 in.,	8.4	2,050	1 90	$3,876		Sand and gravel.
In private land,	1 ft. 8 in.,	8.0	3,750	2 20	8,232		Sand and gravel.
In private land from Washington Street to Boston sewer, Winchester,	2 ft.,	8.2	6,750	4 65	31,353		Sand and gravel.
Land damages,	–	–	–	–	2,900		Twice the assessed value.
						46,361	
Amount carried forward,		–	–	–	–	$2,292,942	

* Total length of pipe.

Estimate of Cost of North Metropolitan Sewerage System — Continued.

SECTION.	Diameter of Sewer.	Average Depth of Excavation. Feet.	Length of Section. Feet.	Approximate Cost per Foot.	Total Cost.	Summary.	Remarks.
Amount brought forward,	–	–	–	–		$2,292,942	
Alewife Brook branch: —							
In private land from Concord Avenue to Spruce Street, Cambridge,	18 in.,	6.0	2,650	$1 91	$5,051		Sand and clay.
In private land to Middlesex Central Railroad,	2 ft. 2 in.,	8.2	1,360	5 03	6,839		Sand and clay.
In private land and Columbus Avenue to North Avenue,	2 ft. 6 in.,	11.1	1,500	6 23	9,345		Sand.
In private land to Broadway, Somerville,	2 ft. 7 in.,	12.8	2,350	6 93	16,275		Sand and mud.
In private land to pumping station,	3 ft. 2 in.,	16.8	3,350	12 36	41,410		Sand and clay, 1,300 lineal feet rock.
Pumping station and machinery,	–	–	–	–	10,000		
In road to Boston Water Works pumping station, and Boston Avenue to Mystic River,	3 ft.,	7.7	1,060	5 88	6,231		Sand and gravel.
Sand-sump and overflow,	–	–	–	–	950		
Siphon under Mystic River,	20 in.,	–	270*	–	3,200		Two lines cast-iron pipe.
In Canal Street to Prescott Street, West Medford,	3 ft.,	16.0	900	7 94	7,150		Sand and gravel.
Land damages,	–	–	–	–	5,500		Three times the assessed value.
						111,951	
Arlington branches: —							
Branch in Decatur Street and branch in Middlesex Central Railroad location,	12 in.,	7.2	750†	3 42	$2,565		Crosses Alewife Brook.
In Charlestown Street,	15 in.,	8.8	150	4 53	680		Crosses Alewife Brook.
Land damages,	–	–	–	–	100		Two to three times assessed value.
						3,345	
West Medford branch, near Jerome Street,	10 in.,	10.2	300	5 65	$1,694		Crosses Mystic River.
						1,694	
Boston Avenue branch, from Medford line,	10 in.,	7.7	550	1 18	$647		Sand and gravel.
						647	

Belmont branch: —							
In private land to Spruce Street, Cambridge,	15 in.,	5.0	4,050	1 36	$5,508		Sand, gravel, clay and 500 lineal feet mud, requiring pile foundation.
Land damages,	–	–	–	–	800		Twice the assessed value.
						6,308	
Melrose branch: —							
In Wyoming Avenue to Waverley Place,	10 in.,	11.3	3,350	2 16	$7,229		Sand and gravel.
In Waverley Place and private land to Winter Street, Malden,	1 ft. 10 in.,	12.9	6,000	3 47	20,834		Sand.
In Linden Avenue to Pleasant Street,	2 ft.,	18.8	2,800	4 50	12,600		Sand, gravel and bowlders.
In Pleasant and Middlesex streets,	15 in.,	9.2	900	1 69	1,518		Sand and gravel.
In Middlesex Street,	1 ft. 8 in.,	12.4	1,300	3 06	3,978		Sand and gravel. Crosses Malden River.
In Green and Tremont streets and private land, Everett,	3 ft. 4 in.,	18.6	6,400	10 34	66,182		Sand and clay, 1,300 lineal feet rock.
Land damages,	–	–	–	–	9,600		Two to three times assessed value.
						121,941	
Edgeworth branch: —							
From Medford line to Third Street, Wellington, in Pearl Street and Cradock Avenue,	2 ft.,	10.9	1,500	5 06	–	7,600	Fine sand. Crosses a creek.
Charlestown branches: —							
From Beach Street to Alford Street in Main Street,	15 in.,	18.6	660	4 98	$3,288		Sand, peat and clay.
From Medford Street to near Vine Street in Chelsea Street,	18 in.,	18.2	1,000	4 90	4,900		Sand, clay and gravel.
In navy yard to junction Wapping and Water streets,	2 ft. 2 in.,	18.1	1,620	6 64	10,751		Sand, clay and gravel.
In Water and Front streets to near Walford Street,	2 ft. 6 in.,	17.6	2,240	9 77	21,889		Sand, clay and gravel.
In Front, Austin and Chapman streets, and Rutherford Avenue to Winchester Street,	2 ft. 7 in.,	22.4	2,800	11 15	31,220		Sand, clay and gravel.
In Rutherford Avenue, from Winchester Street to Cambridge Street,	2 ft. 10 in.,	24.0	3,100	10 47	32,451		Sand, clay and gravel.
Tide-gates and connections,	–	–	–	–	8,100		
						112,599	
Amount carried forward,		–	–	–	–	$2,659,027	

* Total length of pipe.

† Total length of both branches.

Estimate of Cost of North Metropolitan Sewerage System — Continued.

SECTION.	Diameter of Sewer.	Average Depth of Excavation. Feet.	Length of Section. Feet.	Approximate Cost per Foot.	Total Cost.	Summary.	Remarks.
Amount brought forward,		–	–	–	–	$2,659,027	
Cambridge branch: —							
In Mt. Auburn Street, from Lowell Street to Sparks Street,	2 ft.,	14.0	820	$3 48	$2,853		Sand and gravel.
In Mt. Auburn Street to Willard Street,	2 ft. 2 in.,	11.0	560	5 16	2,892		Fine sand.
In Mt. Auburn Street to Bath Street,	2 ft. 4 in.,	16.5	820	8 53	6,998		Gravel, 300 lineal feet mud, requiring pile foundation.
In Mt. Auburn Street to Murray Street,	2 ft. 10 in.,	18.5	1,130	8 34	9,430		Gravel.
In Eliot, South, Holyoke and Mill streets to Charles River Street,	3 ft.,	16.2	1,570	8 06	12,648		Gravel.
In Mill and De Wolf streets, and private land to Western Avenue,	3 ft. 7 in.,	14.6	2,390	8 94	21,376		Sand, gravel and clay.
In Blackstone Street and private land to Pleasant Street,	3 ft. 8 in.,	15.9	2,200	12 08	26,570		Gravel and clay, 700 lineal feet mud, requiring pile foundation.
In private land and Granite Street to Pearl Street,	3 ft. 10 in.,	14.0	1,250	13 83	17,295		Gravel, mud and clay.
In private land, Waverley, Albany and Portland streets to Bristol Street,	4 ft. 2 in.,	17.3	8,330	10 46	87,150		Sand, gravel and mud.
In Portland, Warren and Medford streets to Somerville Avenue,	5 ft. 4 in.,	24.0	3,720	17 50	65,100		Sand and clay.
In Poplar Street, private land, Waverley and Cambridge streets to Sullivan Square,	6 ft.,	27.3	4,900	30 40	148,930		Sand and clay, 2,000 lineal feet rock.
In Sullivan Square and Alford St. to pumping station,	6 ft. 8 in.,	32.4	1,300	33 31	43,300		Clay.
Tide-gates and connections,	–	–	–	–	27,200		
Sand-sump, overflow, pumping station, machinery, wharf, etc.,	–	–	–	–	135,000		
Siphon under Mystic River,	40 in.,	–	1,700*	–	44,600		Two lines cast-iron pipe.

From Mystic River to Paris Street on Alford Street and Broadway,	6 ft., *	21.7	5,700	17 33	98,895		Sand, clay and mud.
Land damages,	–	–	–	–	47,100		
						797,337	
Somerville branch: —							
In Mystic Avenue to Winthrop Avenue,	18 in.,	18.2	4,250	4 26	$18,115		Gravel, clay and mud, 800 lineal feet rock.
In Mystic Avenue, Mousal Place and Arlington Avenue,	2 ft. 6 in.,	22.8	3,300	9 98	32,937		Clay.
In Arlington Avenue to Alford Street,	2 ft. 8 in.,	29.1	700	12 24	8,570		Clay.
Land damages,	–	–	–	–	4,200		
						63,822	
East Boston branches: —							
From Meridian Street to Eutaw Street on Condor and Border streets,	12 in.,	13.5	1,750	2 70	$4,742		Gravel and clay and filling.
From Eutaw Street to Saratoga Street on Border Street,	15 in.,	13.6	1,100	2 92	3,213		Clay.
From Sumner Street to Decatur Street on New, Maverick and Border streets,	12 in.,	14.7	1,300	2 74	3,565		Clay and filling.
From Decatur Street to Saratoga Street on Border Street,	15 in.,	16.6	1,000	3 36	3,360		Gravel filling.
From Border Street to Bremen Street on Porter Street,	1 ft. 7 in.,	19.7	1,700	4 44	7,558		Sand.
In Marginal and Orleans streets to Maverick Street,	12 in.,	15.5	2,650	3 11	8,253		Clay, sand and mud.
From Sumner Street to Maverick Street on Jeffries Street,	12 in.,	11.2	500	2 01	1,005		Clay and gravel.
In Maverick and Bremen streets to Porter Street,	15 in.,	16.5	4,150	3 78	15,707		Sand mud and clay.
In Bremen Street to Brooks Street,	2 ft. 10 in.,	22.7	1,400	9 36	13,102		Sand and clay.
In Bremen, Prescott and Chelsea streets to main sewer,	3 ft. 2 in.,	28.5	4,850	12 14	58,920		Hard sand and gravel.
In Eagle Street to Chelsea Street,	12 in.,	20.0	250	4 04	1,010		Sand and clay.
Tide-gates and connections,	–	–	–	–	11,200		
						131,635	
Chelsea branch: —							
In Eastern Avenue from Willowby Street to Marginal Street,	2 ft. 4 in.,	17.8	3,100	10 16	–	31,500	Sand and clay, 2,600 lineal feet mud, requiring pile foundation, 2 tide-gates and sewer connections.
Amount carried forward,	–	–	–	–	–	$3,683,321	

* Total length of pipe.

Estimate of Cost of North Metropolitan Sewerage System — Concluded.

SECTION.	Diameter of Sewer.	Average Depth of Excavation. Feet.	Length of Section. Feet.	Approximate Cost per Foot.	Total Cost.	Summary.	Remarks.
Amount brought forward,	-	-	-	-	-	$3,683,321	
Mystic Valley sewer, built by the city of Boston: —							
Portion from Woburn town line to Lower Mystic Lake,	-	-	-	-	-	68,000	Includes 2,814 feet of 15 inch pipe and 11,456 feet brick sewer and iron pipe.
Structures and apparatus for measuring sewage,	-	-	-	-	-	30,000	
						$3,781,321	
Engineering, administration and contingencies, ten per cent.,	-	-	-	-	-	378,132	
Total first cost of works,	-	-	-	-	-	$4,159,453	
Estimated additions to works up to A. D. 1930,							
For increased pumping machinery,	-	-	-	-	$97,000		
One outlet pipe and enlarging chamber,	-	-	-	-	75,000		
Siphons,	-	-	-	-	32,000		
						204,000	
Engineering, administration and contingencies, ten per cent.,	-	-	-	-	-	20,400	
Total cost of works to A. D. 1930,	-	-	-	-	-	$4,383,853	

In the foregoing estimates are included the cost of the intercepting sewers of Cambridge, Charlestown, East Boston and the east side of Chelsea, which are as follows: —

Cambridge sewers: —		
Upper portion of Alewife Brook branch, from Concord Avenue to a point near Spruce Street,	$4,875	
Land damages,	600	
Upper portion of Cambridge branch, from near Lowell Street to a point near the Somerville town line,	224,134	
Land damages,	32,000	
Tide-gates and connections,	17,000	
	$278,609	
Engineering, administration and contingencies, ten per cent.,	27,861	
Total for Cambridge,		$306,470
Charlestown sewers: —		
From Beach Street in Main Street to a point near the Cambridge branch in Alford Street,	$2,790	
From the junction of Medford and Chelsea streets to a point near the Cambridge branch in Cambridge Street,	99,802	
Tide-gates and connections,	8,100	
	$110,692	
Engineering, administration and contingencies, ten per cent.,	11,069	
Total for Charlestown,		121,761
East Boston sewers: —		
Total of all branches to a point near the main intercepting sewer,	$119,175	
Tide-gates and connections,	11,200	
	$130,375	
Engineering, administration and contingencies, ten per cent.,	13,038	
Total for East Boston,		143,413
Chelsea sewer: —		
From Willowby Street in Eastern Avenue to a point near the main intercepting sewer,	$31,500	
Engineering, administration and contingencies, ten per cent.,	3,150	
Total for Chelsea,		34,650
		$606,294

Main Sewer for the Lower Charles River Valley.

At your request, the sizes and route for an intercepting sewer for the lower Charles River valley, with an outlet in the Boston intercepting sewer, have been studied. The sewer is designed to have a carrying capacity of 30 cubic feet per head per day for the estimated population in 1930. The table below gives the estimated populations of the towns and cities provided for, and the corresponding quantities of sewage.

TOWNS AND CITIES.	Cubic Feet per Head per Day.	Population, 1885.	Estimated Population, 1930.	Cubic Feet per Second, 1930.
Waltham, ...	80	14,609	33,000	11.5
Watertown, . . .	80	6,238	11,200	3.9
Newton, ...	80	19,759	44,800	15.6
Brighton, ...	80	8,523	18,000	6.3
Brookline, . . .	80	9,196	16,800	5.8
Part of Boston, . . .	80	19,000	34,000	11.7

After a careful examination in the field, the route selected for this sewer is substantially a portion of that adopted by the commission of 1885, but the sizes, depths and inclinations are somewhat different. It begins in North Street, Waltham, near the Newton boundary line, with a diameter of 3 feet 9 inches and a slope of 1 in 1,500. Its invert is 21½ feet above approximate mean low water of Boston harbor. This sewer, as designed, affords a practicable outlet for the projected Waltham sewers designed by Mr. Bowditch.

From North Street the sewer proceeds in Farwell Street and nearly parallel to the river through private lands to Bridge Street.

The sewage is designed to be carried across Cheesecake Brook in an iron pipe. Carefully arranged culverts will be necessary at this and several other small water courses on the line of the proposed sewer. From Bridge Street the sewer continues in California Street for about 1,100 feet with an inclination of 1 in 1,500. It then descends about 7½ feet in a distance of 800 feet. At the foot of this descent the bottom of the sewer will be about 24 feet below the surface of the ground. Considerable excavation would be saved by making this descent 700 feet farther east, but the designed arrangement affords a better outlet for a portion of the Watertown sewage from the north side of the river. The diameter of the main is here increased to 4 feet 2 inches and its inclination flattened to 1 in 2,500. This inclination is maintained to the end of the proposed sewer, and is the greatest that will allow connection with the Boston intercepting sewer already built. The sewers discharging into the Charles River valley sewer above Brighton are not intended to carry storm water, and will not, therefore, bring in street washings. If these and the intercepting sewer are

well built, only slight deposits if any are likely to occur, and these can be moved by flushing to lower sections of the sewer, where the volume and velocity of flow is greater.

At Galen Street another branch from the north side of the river will probably enter the main, and the latter has its diameter increased to 4 feet 6 inches. The sewer then passes through Galen Street to Water Street, and in the latter to near Parker's starch factory. To avoid temporary and perhaps permanent injury to the springs which supply the water used in making starch, the sewer line is here located in the edge of the river, outside of the factory buildings, for a distance of about 600 feet. An allowance is made in the estimate for a river wall, and the filling necessary to protect the sewer. The location of the sewer, below the factory, lies near the river bank to a point about a quarter of a mile beyond Lemon Brook.

The route is then along the north side of the Boston and Albany Railroad embankment to North Beacon Street. For a part of this section mud is found extending a short distance below the sewer. This can be removed and replaced with hard material. The sewer here will require additional masonry. The line then passes through private ways along the margin of the river, and between it and the buildings of the Brighton abattoir, to Market Street. Pockets of mud are found in this vicinity, and allowance has been made for about 1,000 feet of pile foundation. At Market Street the invert of the sewer is 4 feet 2 inches above low water, and its diameter is increased to 4 feet 10 inches. From this point the sewer proceeds in Western Avenue to about 600 feet beyond its junction with North Harvard Street. It then runs through projected streets and private lands to Cambridge Street opposite Beacon Park, and across the park to the marsh just north of the Boston and Albany Railroad.

An alternative route from the junction of North Harvard Street and Western Avenue is found by following North Harvard Street to Cambridge Street and thence across the park and marsh. The excavation would be somewhat greater by this route, but it may be followed if the land damages are likely to be excessive by the former. The route of the sewer then lies between the railroad and the river, passing over another mud pocket where pile foundations will be required, to Cottage Farm station at Essex Street. Several sewers are intercepted in Brighton whose lower ends can be used as overflows. From Essex Street the sewer follows Commonwealth Avenue to St. Mary's Street, and its diameter is here increased to 5 feet 6 inches, the invert being 1 foot below low water. The large sewer from Brookline is passed under at

this place, and the sewage from it received. A suitable connection between the two sewers will allow the lower end of the Brookline sewer to be used as an overflow from the intercepting sewer. When the Brookline sewer was constructed, much ground water was met at this point. It is probable that the coarse gravel found in various places on the route of the intercepting sewer, between here and Waltham, will also yield much water, and require considerable pumping plant when the sewer is constructed.

The intercepting sewer turns from Commonwealth Avenue into St. Mary's Street and passes in that and its proposed extension, across Muddy River to Brookline Avenue. It then follows along a driveway on the southerly border of the Back Bay Park, and passes through a small piece of private land to Huntington Avenue. Near Muddy River and in the park deep beds of mud will be met, where pile foundations will be required. The sewer proceeds in Huntington Avenue to Parker Street, where its diameter is increased to 6 feet 6 inches. At this place it passes under the new Stony Brook conduit. The section under the conduit is now being built in a substantial manner by the city of Boston, in connection with the conduit itself. This section is about 70 feet long, and consists of two circular sewers each 4 feet 8 inches in diameter, united by a bell mouth at each end to the 6 feet 6 inch sewer. The sewer continues through Huntington Avenue to Camden Street, where it joins the main sewer of the city of Boston.

The estimated cost of constructing the sewer for the relief of the lower Charles River valley is presented on the opposite page.

HOWARD A. CARSON,
Civil Engineer.

Estimate of Cost of Lower Charles River Valley Sewer.

SECTION.	Diameter of Sewer.	Average Depth of Excavation. Feet.	Length of Section. Feet.	Approximate Cost per Foot.	Total Cost.	Summary.	Remarks.
In North Street, Farwell Street, private land, and California Street to near Crescent Street, Newton, . .	3 ft. 9 in.,	13.0	6,050	$10 60	$64,130		Wet gravel and bowlders. Culvert and channel for Cheesecake Brook.
In California and Watertown streets to Galen Street, Watertown, ...	4 ft. 2 in.,	14.4	3,300	11 30	37,290		Sand, clay, wet gravel and bowlders. Two culverts and change of channel.
From Galen Street in Water Street, and private land to Market Street, Brighton, ...	4 ft. 6 in.,	10.3	12,300	14 10	173,430		Sand, clay, mud and gravel, 600 feet of river wall and filling, 3,600 lineal feet requiring pile or other extra foundations.
From Market Street in Western Avenue, Rena Street, private land, and Commonwealth Avenue to St. Mary's Street, ...	4 ft. 10 in.,	16.1	12,900	14 80	190,920		Wet gravel and mud, 2,300 lineal feet requiring pile or other extra foundations.
From Commonwealth Avenue in St. Mary's Street, park and private lands, and Huntington Avenue to Parker Street, Boston, ...	5 ft. 6 in.,	19.6	6,700	22 00	147,400		Sand, clay, mud and gravel, 3,500 lineal feet requiring pile or other extra foundations.
From Parker Street to Camden Street, in Huntington Avenue, ...	6 ft. 6 in.,	24.0	1,900	28 40	53,960		Sand, clay and gravel, 800 lineal feet of mud.
Land damages, ...	–	–	–	–	64,000		
						$731,130	
Engineering, administration and contingencies, ten per cent., ...	. . .	–	–	–	–	73,113	
						$804,243	

APPENDIX.

Estimated Cost of Construction of North Metropolitan Sewerage System, in case Storage Reservoir is built.

First cost of works, without reservoir (less contingencies, etc.),	$3,781,321	
Reservoir,	326,000	
Additional land damages,	5,000	
Additional pumping machinery,	14,000	
Additional outlet pipe,	57,000	
		$4,183,321
Engineering, administration and contingencies, ten per cent.,	–	418,332
Total first cost of works, with reservoir,	–	$4,601,653
Estimated cost of additions to works up to A. D. 1930:—		
First cost as above (less contingencies, etc.),	$4,183,321	
Increased pumping machinery,	105 000	
Enlarging reservoir,	175,000	
Two outlet pipes and enlarging chamber,	138,000	
Land and dwellings,	8,000	
Siphons,	32,000	
		$4,641,321
Engineering and contingencies,	–	464,132
	–	
Total cost of works, with reservoir,	–	$5,105,453

Preliminary Designs.

Before making the design and estimate for the North Metropolitan Sewerage System, three systems of sewerage were designed, each of which provides outlets for towns of the Mystic valley, East Boston and Chelsea, but makes no provision for Charlestown and the larger part of Cambridge and Somerville. One of these systems provides for Revere and one for Winthrop. Brief descriptions and estimates of cost of these systems follow.

Limited System of Sewers discharging at Deer Island.

All the branches of the North Metropolitan System of sewers, except the Cambridge, Charlestown and Somerville branches, are included without change in this limited system. The Mystic valley sewer from the Woburn town line to Mystic Lake, and the main sewer from Mystic Lake to the junction of Paris Street and Broadway, Everett, are also included without change. The main sewer below Broadway follows the same route, has the same inclinations and the same locations of pumping stations as those of the North Metropolitan System. The sizes of this

main and the capacities of the pumping stations are less on account of the omission of the branches named above. From Broadway to the junction of Second and Spruce streets in Chelsea the diameter is 5 feet 10 inches. From Spruce Street to the junction of Marginal Street and Eastern Avenue the diameter is 6 feet 4 inches. The sewage is carried under the Chelsea River to near the East Boston pumping station by one line each of 3 and 4 feet pipe. The lift at this pumping station is about 17½ feet. From this station to the pumping station on Deer Island the sewer has a uniform size of 7 feet. The siphons at Belle Isle Inlet and Shirley Gut in the limited system consist each of two lines of 4 feet pipe, the same as in the larger system. The former have somewhat less costly chambers, and would need no increase in capacity for forty years. The outlet of this system, as designed, consists of two lines of pipe 4 feet in diameter, terminating near Deer Island Beacon. If the sewage is discharged continuously, it is estimated that this outlet would need no increase in capacity for forty years. If the sewage is stored in a reservoir and discharged only during the first five hours of the outward current of each tide, an additional line of pipe would be required in about twenty years.

Estimate of Cost of Limited Sewerage System having outlet at Deer Island and providing inlets for Woburn, Stoneham, Winchester, Arlington, Belmont, one-fifth of Somerville, one-ninth of Cambridge, Medford, Melrose, Malden, Everett, Chelsea, East Boston and Winthrop.

SECTION.	Diameter of Sewer.	Average Depth of Excavation. Feet.	Length of Section. Feet.	Approximate Cost per Foot.	Total Cost.	Summary.	Remarks.
Main intercepting sewer from Mystic Lake to Broadway and Paris Street, Everett, same as in North Metropolitan Sewerage System. Also the following branches: Cummingsville, Stoneham, Belmont, Alewife Brook, Arlington, Boston Avenue, West Medford, Edgeworth and Melrose, — all as in North Metropolitan Sewerage System,	-	-	-	-	$633,948		
From Broadway, Everett, in Paris Street, marsh and Second Street to Spruce Street, Chelsea,	5 ft. 10 in.,	20.5	5,700	$26 06	148,543		Clay, sand and gravel, 2,700 lineal feet mud, requiring pile foundation.
From Spruce Street in Second, Winnisimmet and Marginal streets to Chelsea River near Eastern Avenue,	6 ft. 4 in.,	29.0	7,100	28 85	204,868		Clay, sand and gravel, 3,000 lineal feet mud.
Tide-gates and connections in Chelsea,	-	-	-	-	12,000		
Sand-sump, etc., in Chelsea, near Chelsea River,	-	-	-	-	11,000		
Siphon under Chelsea River,	3 ft., 4 ft.,	-	830*	-	23,000		One line of 3 feet pipe, and One line of 4 feet pipe.
From Chelsea River to pumping station,	7 ft.,	28.8	150	26 86	4,029		Clay and gravel.
East Boston pumping station, machinery, sheds, wharf, sand-sump, etc.,	-	-	-	-	140,000		
From pumping station in Addison and Saratoga streets, Butler Avenue, Faxon Street and marsh to Belle Isle Inlet,	7 ft.,	13.6	7,500	20 92	156,884		Clay, sand and gravel, 2,800 lineal feet mud.

Sand-sump and overflow at Belle Isle Inlet,	–	–	–	–	8,300		
Siphon under Belle Isle Inlet,	4 ft.,	–	1,300*	–	42,000		Two lines of cast-iron pipe.
From Belle Isle Inlet, in private land, Main Street, marsh, and Shirley Street to Shirley Gut,	7 ft.,	17.5	14,180	23 14	328,152		Clay, sand and gravel, 2,100 lineal feet mud, requiring foundation.
Sand-sump and overflow at Shirley Gut,	–	–	–	–	10,500		
Siphon under Shirley Gut,	4 ft.,	–	600*	–	27,000		Two lines of cast-iron pipe.
On Deer Island, from Shirley Gut to pumping station,	7 ft.,	23.2	4,100	26 52	108,727		Sand, gravel and clay.
Deer Island pumping station, machinery, sheds, wharf, dwellings, etc.,	–	–	–	–	140,000		
Outfall sewer from pumping station to gate chamber,	†	17.5	1,000	20 00	20,000		Sand, gravel and clay.
Gate chamber and outfall pipe lines,	4 ft.,	–	4,000*	–	143,000		Two lines of cast-iron pipe.
Land damages, Deer Island,	–	–	–	–	10,000		
Land damages, main intercepting sewer,	–	–	–	–	54,000		
						$2,225,951	
East Boston branches: —							
Same as in North Metropolitan Sewerage System,	–	–	–	–	–	131,635	
Chelsea branch: —							
Same as in North Metropolitan Sewerage System,	–	–	–	–	–	31,500	
Mystic Valley sewer: —							
Same as in North Metropolitan Sewerage System,	–	–	–	–	–	68,000	
Structures and apparatus for measuring sewerage,	–	–	–	–	–	22,000	
						$2,479,086	
Engineering, administration and contingencies, ten per cent.,	–	–	–	–	–	247,909	
Total first cost of works,	–	–	–	–	–	$2,726,995	
Estimated cost of additions to works up to A. D. 1930: —							
Increased pumping machinery,	–	–	–	–	$60,000		
Engineering and contingencies, ten per cent.,	–	–	–	–	6,000		
						66,000	
Total cost of works to A. D. 1930,	–	–	–	–	–	$2,792,995	

* Total length of pipe.

† Varying size.

Estimate of Cost of Limited Sewerage System having outlet at Deer Island, etc. — Concluded.

SECTION.	Diameter of Sewer.	Average Depth of Excavation. Feet.	Length of Section. Feet.	Approximate Cost per Foot.	Total Cost.	Summary.	Remarks.
Estimated cost in case storage reservoir is built: —							
First cost of works,	–	–	–	–	$2,479,086		
Reservoir,	–	–	–	–	200,000		
Additional land damages,	–	–	–	–	5,000		
Additional equipment for pumping station,	–	–	–	–	9,000		
						$2,693,086	
Engineering, administration and contingencies, ten per cent.,	–	–	–	–	–	269,309	
Total first cost of works, with reservoir,	–	–	–	–	–	$2,962,395	
Estimated cost of additions to works up to A. D. 1930: —							
Increased pumping machinery,	–	–	–	–	$65,000		
Enlarging reservoir,	–	–	–	–	130,000		
Additional outlet pipe and cost of enlarging chamber,	–	–	–	–	70,000		
Engineering and contingencies, ten per cent.,	–	–	–	–	26,500		
						291,500	
Total cost of works, with reservoir, to A. D. 1930,	–	–	–	–	–	$3,253,895	

LIMITED SEWERAGE SYSTEM CENTERING AT CHEMICAL PRECIPITATION STATION NEAR ISLAND END RIVER.*

In this system the main sewer and all of the branches above the junction of Paris Street and Broadway, Everett, are identical with those in the North Metropolitan Sewerage System. At Paris Street the main sewer turns to the right and proceeds in Broadway to a point opposite Beacham Street, then turns to the left and passes in Beacham Street and private land for a distance of 3,500 feet to the chemical precipitation station near Island End River. The sewer between Paris Street and the point just mentioned has a diameter of 5 feet 8 inches, and a fall of 1 in 2,500. Its invert at the precipitation station is $8\frac{2}{10}$ feet below low water.

The East Boston branches are identical with those in the North Metropolitan Sewerage System, except that the main in Chelsea Street is somewhat shorter. The East Boston sewage is carried across the Chelsea River in a line of iron pipe 3 feet in diameter, about 900 feet west of the Chelsea Street bridge. The main then passes through Marginal and Williams streets in Chelsea to Spruce Street, and there turning to the left, proceeds in nearly a straight line across Island End River to the precipitation station previously mentioned. The diameters of the section just described are: 4 feet from the East Boston siphon to Pearl Street, 4 feet 4 inches from Pearl Street to Spruce Street, and 4 feet 6 inches from the latter to the precipitation station. The invert of this section is 11 feet below low water at Pearl Street, and $12\frac{1}{2}$ feet below at the precipitation station. The inclination is 1 in 2,500.

* A report upon the system of disposal by chemical precipitation, by Charles H. Swan, C. E., may be found upon page 112 of this document.

Estimate of Cost of Limited Sewerage System centering at Chemical Precipitation Station near Island End River, and providing inlets for Woburn, Stoneham, Winchester, Arlington, Belmont, one-fifth of Somerville, one-ninth of Cambridge, Medford, Melrose, Malden, Everett, Chelsea and East Boston.

SECTION.	Diameter of Sewer.	Average Depth of Excavation. Feet.	Length of Section. Feet.	Approximate Cost per Foot.	Total Cost.	Summary.	Remarks.
Main intercepting sewer from Mystic Lake to Broadway and Paris streets, Everett, same as in North Metropolitan Sewerage System. Also the following branches: Cummingsville, Stoneham, Belmont, Alewife Brook, Arlington, Boston Avenue, West Medford, Edgeworth and Melrose, — all as in North Metropolitan Sewerage System, ...	–	–	–	–	$633,948		
From Paris Street in Broadway, private land, and Beacham Street to precipitation station, . . .	5 ft. 7 in.,	21.7	5,420	$15 56	84,367		Clay.
Land damages on main intercepting sewer, . . .	–	–	–	–	33,000		
						$751,315	
East Boston branches: —							
South and west of junction of Brooks and Bremen streets, and branch in Eagle Street at Eagle Square, same as in North Metropolitan Sewerage System,	–	–	–	–	$61,515		
In Bremen, Prescott and Chelsea streets, from Brooks Street to siphon opposite Glendon Place at Chelsea River, ...	3 ft. 2 in.,	26.6	3,300	11 90	39,270		Clay and gravel.
Siphon under Chelsea River, ...	3 ft., . .	–	940	–	25,000		One line of cast-iron pipe.
Tide-gates and connections in East Boston, . .	–	–	–	–	11,400		
Sand-sump, etc., in East Boston at Chelsea River, .	–	–	–	–	11,000		
						148,185	

Chelsea branch: —							
From Willowby Street, in Eastern Avenue and Marginal Street, to siphon from East Boston,	2 ft. 4 in.,	18.0	4,000	10 15	–	40,600	Sand and clay, 3,500 lineal feet of mud, requiring pile foundation. Two tide-gates and sewer connections.
Main sewer in Chelsea: —							
From East Boston siphon to Pearl Street, in Marginal Street,	4 ft.,	27.3	3,550	12 64	$44,866		Sand and clay, 3,000 lineal feet of mud.
From Pearl Street in William Street to Spruce Street,	4 ft. 4 in.,	35.7	2,300	20 70	47,610		Sand and gravel.
In marsh land, from Spruce Street to precipitation station,	4 ft. 6 in.,	23.6	2,430	23 00	55,890		Crosses Island End River.
Tide-gates and connections in Chelsea,	–	–	–	–	12,300		
						160,666	
Mystic valley sewer: —							
Same as in North Metropolitan Sewerage System,	–	–	–	–	–	68,000	
Structures and apparatus for measuring sewage,	–	–	–	–	–	20,000	
						$1,188,766	
Engineering, administration and contingencies, ten per cent.,	–	–	–	–	–	118,877	
						$1,307,643	
Precipitation works, Mr. Swan's estimate,	–	–	–	–	$978,964		
Engineering, administration and contingencies, ten per cent.,	–	–	–	–	97,896		
						1,076,860	
						$2,384,503	

Limited System of Sewers Discharging upon Saugus Marshes for Filtration, and into Pines River. *

All of the main sewer and branches above Central Square, Medford, in the North Metropolitan Sewerage System, are included without change in this. Leaving Central Square, the main sewer follows the route adopted by the commission of 1885 through Salem, Charles and Main streets to the Saugus Branch Railroad, Malden; thence along the southerly side of the railroad through Maplewood and Linden to the Revere boundary line. Thence it extends about a mile across marsh land to a pumping station and filtration area in the edge of Saugus just north of the Pines River.

The main sewer from Central Square has successively the diameters 4 feet 7 inches, 5 feet 5 inches, and at Broadway, Malden, 5 feet 7 inches, which size is maintained to the pumping station. The invert of the main sewer at Middlesex Street, Malden, is 1½ feet below low water, and at the pumping station near the Pines River is $8\frac{9}{10}$ feet below.

The Melrose branch is the same as that in the North Metropolitan Sewerage System from the Stoneham town line to the junction of Middlesex and Charles streets, where it enters the main sewer.

The Everett branch follows the same route as that adopted by the commission of 1885. Starting at the junction of Broadway and Main Street in Everett, with a diameter of 2 feet 2 inches, and an elevation of 6½ feet above low water, it follows the westerly side of the Saugus Branch Railroad to the main sewer at the junction of Middlesex and Charles streets. Its inclination is 1 in 1,800.

The Chelsea and Revere branch follows the same route, and has the same inclinations as were adopted by the commission of 1885. Starting at Spruce Street, it follows Williams and Marginal streets and Eastern Avenue to the Eastern Railroad. Thence it is located just south of the railroad to near Mill Creek. Here it crosses the tracks to the north side, and passes under the creek by a double line of 3 feet iron pipe. The sewer then follows along the railroad to beyond Revere Street, and, turning north, crosses the marsh to the pumping station at the filtration area.

The invert at Spruce Street is about 6½ feet above low water. The sewer here is oval, 2 feet 10 inches by 4 feet 2 inches. At Eastern Avenue and Marginal Street, where a branch from East Boston enters, it changes to a circular sewer 4 feet 4 inches in

* The results of experiments, having for their object the determination of the capability of the Saugus marshes for sewage filtration, may be found in the report of Fred. Brooks, C. E., on page 121.

diameter. From near Beach Street to the pumping station it has a diameter of 4 feet 8 inches. The invert at the station is 7 feet below low water.

The East Boston intercepting sewers for this system are the same in all respects as in the North Metropolitan Sewerage System, except that the main in Chelsea Street is extended 150 feet to the pumping station. This pumping station is located on the same site as that chosen for the North Metropolitan Sewerage System. Here the sewage is lifted about 15½ feet, and is then carried under the river by a single line of 3 feet iron pipe, and joins the Chelsea and Revere branch already described.

Estimate of Cost of Limited Sewerage System discharging upon Saugus Marshes for filtration, and into Pines River, and providing inlets for Woburn, Stoneham, Winchester, Arlington, Belmont, one-fifth of Somerville, one-ninth of Cambridge, Medford, Melrose, Malden, Everett, Chelsea, East Boston and Revere.

SECTION.	Diameter of Sewer.	Average Depth of Excavation. Feet.	Length of Section. Feet.	Approximate Cost per Foot.	Total Cost.	Summary	Remarks.
Main intercepting sewer from Mystic Lake to Central Square, Medford Centre, same as in North Metropolitan Sewerage System. Also the following branches: Cummingsville, Stoneham, Belmont, Alewife Brook, Arlington, Boston Avenue and West Medford, — all as in North Metropolitan Sewerage System,	-	-	-	-	$310,435		
From Central Square, in Salem Street, private land and Charles Street, to Middlesex Street, Malden,	4 ft. 7 in.,	19.7	11,400	$11 68	133,240		Sand and gravel. Crosses Malden River.
From Middlesex Street, in Charles Street and along Saugus Branch R.R. to Broadway, Malden,	5 ft. 5 in.,	20.2	8,700	17 85	155,254		Sand, 1,200 lineal feet mud, requiring pile foundation 1,300 lineal feet rock.
From Broadway, along Saugus Branch R.R. and in private land to pumping station,	5 ft. 7 in.,	21.9	9,300	14 40	133,920		Sand and clay.
Pumping station, machinery, etc.,	-	-	-	-	150,000		
Land damages,	-	-	-	-	31,000		
						$913,849	
Melrose branch: —							
From Stoneham town line at Wyoming Avenue to Middlesex Street, Malden, same as in North Metropolitan Sewerage System,	-	-	-	-	$42,181		
In Middlesex Street to the main sewer in Charles Street,	1 ft. 8 in.,	12.4	1,100	3 00	3,300		Sand and gravel. Crosses Malden River.

Land damages,	–	–	–	–	4,600	50,081	
Everett branch:—							
From the junction of Broadway and Main Street, Everett, to and along the Saugus Branch R.R. to main sewer at Middlesex Street, Malden,	2 ft. 2 in.,	10.0	9,400	6 60	$62,040		Clay, 4,000 lineal feet mud, requiring pile foundation.
Land damages,	–	–	–	–	1,000	63,040	
East Boston branches, south and west of junction of Brooks and Bremen streets, and branch at Eagle Square, same as in North Metropolitan Sewerage System,	–	–	–	–	$61,515		
From Brooks Street, in Bremen, Prescott and Chelsea streets, to pumping station,	3 ft. 2 in.,	28.6	5,000	12 18	60,875	–	Sand, gravel and stones.
East Boston pumping station, machinery, sheds, wharf, sand-sump, etc.,	–	–	–	–	51,000		
Tide-gates and connections in East Boston,	–	–	–	–	11,000		
Siphon under Chelsea River,	3 ft.,	–	420	–	16,000	–	One line of cast-iron pipe.
From Chelsea River to main sewer in Eastern Avenue,	3 ft. 2 in.,	10.7	200	16 23	3,246	–	Mud requiring pile foundation.
Land damages,	–	–	–	–	10,000	213,636	For pumping station.
Chelsea and Revere branch:—							
From Spruce Street in Williams and Marginal streets to Eastern Avenue,	2 ft. 10 in., ×4 ft. 2 in.,	15.8	6,600	11 55	$76,230	–	Sand and gravel, 3,300 lineal feet mud, requiring pile foundation.
In Eastern Avenue and along Boston and Maine R.R. to near Beach Street, Revere,	4 ft. 4 in.,	16.6	10,400	14 65	152,360	–	Sand, gravel and clay, 5,600 lineal feet mud, requiring pile foundation. Double line iron pipe under Mill Creek.
From near Beach Street along Boston and Maine R.R., and in private land, to Saugus pumping station,	4 ft. 8 in.,	19.0	11,400	11 50	131,100	–	Sand, gravel and clay.
Tide-gates and connections in Chelsea,	–	–	–	–	20,000	–	Part of Spruce Street sewer to be rebuilt.
Land damages,	–	–	–	–	5,000	384,690	
Amount carried forward,		–	–	–	–	$1,625,296	

Estimate of Cost of Limited Sewerage System discharging upon Saugus Marshes, etc. — Concluded.

SECTION.	Diameter of Sewer.	Average Depth of Excavation. Feet.	Length of Section. Feet.	Approximate Cost per Foot.	Total Cost.	Summary.	Remarks.
Amount brought forward,		–	–	–	–	$1,625,296	
Mystic valley sewer, same as in North Metropolitan Sewerage System,		–	–	–	–	68,000	
Structures and apparatus for measuring sewage,		–	–	–	–	20,000	
						$1,713,296	
Engineering, administration and contingencies, ten per cent.,		–	–	–	–	171,330	
						$1,884,626	
Filtration area: —							
1,000 acres of land (assuming Saugus marshes suitable for the purpose),		–	–	–	$100,000		
Preparation of land,		–	–	–	600,000		
						700,000	
Engineering, administration and contingencies, ten per cent.,		–	–	–	–	70,000	
						$2,654,626	

SPECIAL REPORTS OF THE CHIEF ENGINEER OF THE BOARD.

To Mr. HIRAM F. MILLS, *Chairman Committee on Water Supply and Sewerage.*

SIR: — In accordance with your request that I should make final reports upon such matters relating to the disposal of the sewage of the Mystic and Charles River valleys as have been specially referred to me, I herewith respectfully submit reports upon the following subjects: —

1. The ability of the Boston Main Drainage Works to dispose of sewage from cities and towns outside of Boston, and to what extent.
2. The present operation of the Main Drainage Works, with reference to the outlet.
3. The methods by which each city or town in the North Metropolitan Sewerage District may provide for itself a system of sewers having an outlet into the main system.
4. Independent systems of sewerage for the cities and towns in the North Metropolitan Sewerage District.
5. Estimated cost of sewerage systems for the North Metropolitan and Mystic valley districts.

To report upon subjects 3 and 4 required extended surveys and investigations; and, as my time has been very fully occupied by other work of the Board, these surveys and investigations, and the plans for the sewerage of the several communities, have been made by Mr. William M. Brown, Jr., with only a general supervision on my part.

THE ABILITY OF THE BOSTON MAIN DRAINAGE WORKS TO DISPOSE OF SEWAGE FROM CITIES AND TOWNS OUTSIDE OF BOSTON, AND TO WHAT EXTENT.

The Boston Main Drainage Works were designed to take the dry-weather flow of the common sewers, and in addition a portion of the surface water from storms or melting snow, any surplus

above the capacity of the works being discharged by overflowing through the outlets of the common sewers. The territory considered in designing these works includes not only the whole city of Boston, with the exception of Charlestown and East Boston, but also the whole of Brookline and Newton, and the portions of Hyde Park, Dedham, Waltham and Watertown included in the district bounded by the Charles and Neponset rivers and Mother Brook.

Provision was made in the designs for taking the sewage from the higher portions of this territory to the outlet, without pumping, by means of a "high-level" intercepting sewer, and the portions of the works in the vicinity of the outlet were constructed with this in view. As the territory to be sewered by the "high-level" sewer contained too small a population to warrant its construction in the near future, the low-level system was designed and constructed on a liberal scale, to meet the requirements of the whole district for a long time.

The practical operation of the works at the present time is as follows: When no water from rain or melting snow enters the sewers, the volume of sewage flowing in them varies in amount from 30,000,000 to 42,000,000 gallons per day, averaging about 36,000,000. The total capacity of the works at present is at the rate of about 112,000.000 gallons per day, so that at the present time the amount of storm water that can be disposed of is about 76,000,000 gallons, in addition to the sewage proper.

As the sewers under ordinary conditions do not run more than one-quarter full, they will, on account of this large storage capacity, take care of storm water for a short time at a greater rate than above stated.

In designing the works, it was assumed for the purposes of estimate that the storm water to be taken care of was a uniform amount per acre from all parts of the area sewered; but it was then the intention, and is now the practice, to favor certain low districts, where the cellars are liable to be flooded during heavy rains at high tide. When there is only a light rain, so that the whole amount entering the sewers can be pumped, the storm water from all districts is taken care of. When the volume is so great as to exceed to a small extent the capacity of the works, regulators controlling the flow of all sewers except those from the low districts begin to close, and cause a part of the diluted sewage to discharge through the old outlets into the harbor. With a greater amount of storm water entering the sewers, the different regulators close one after another, until, during storms of considerable magnitude, all are closed, and the whole capacity of

the works is devoted to taking storm water and sewage from the low districts, together with an unavoidable small amount of leakage past each regulator.

If, in extending the system, the sewers are built to take storm water, and are provided with regulators and overflows according to the present system, the effect will be to cause all of the overflows, except from the low districts, to operate with smaller and smaller storms, until finally, if the dry-weather flow should nearly equal the capacity of the works, it would take but a light rain or a small thaw to bring the overflows into use. Extensions of this kind, though objectionable if so great as to cause too much sewage to overflow into the harbor, would not affect the capacity of the works to take care of these low districts during heavy storms, except by the amount of water leaking past the added regulators.

If, on the other hand, storm water is excluded from sewers built in extending the system, as is proposed for districts not now sewered, and these sewers are allowed to discharge freely into the main system at all times, the capacity of the works to take care of storm water from the low districts will be reduced by the amount of sewage so admitted. The amount of sewage brought to the works in this way will never be large enough to affect seriously the drainage of the low districts, and a decision as to the amount of population and territory which can be served by this Main Drainage System will depend chiefly upon the provision which may be made for storm water, to prevent the overflows from operating to too great an extent.

To determine how much population and territory can be added to the system without encroaching too much upon the margin left for storm water, it is necessary to consider, in some detail: —

1. The capacity of the Main Drainage Works at present, and when developed.
2. The volume of sewage to be allowed per inhabitant.
3. The present and prospective population of the territory which it is feasible to provide for by an extension of the Main Drainage Works.

The Capacity of the Main Drainage Works at Present, and when Developed.

As before stated, the works at the present time can convey to Moon Island 112,000,000 gallons of sewage and storm water per day. This limit is fixed by the carrying capacity of a temporary wooden flume from Squantum to Moon Island. It is the design to replace this perishable structure by a permanent masonry

sewer of large capacity, so that this limit will be removed within a few years, regardless of any need for increasing the capacity of the works. When this is done, the limit will be fixed by the present pumping capacity of about 124,000,000 gallons per day.

With the view of determining the capacity of the works when fully developed, the different parts have been examined in detail, and the principal results will be presented.

Reservoir. — The reservoir at Moon Island will hold 25,000,000 gallons. It is the custom to store the sewage during the incoming and portions of the outgoing tide, the reservoir being emptied and flushed during about two hours in the early part of the outgoing tide, when the currents are most favorable. As the storage takes place during only about ten hours between tides, the sewage can be received into the reservoir at an average rate of 2,500,000 gallons per hour, or 60,000,000 gallons per day. The currents past this outlet are sufficiently favorable, for fully four hours of each tide, to warrant the discharge of sewage during this time whenever the flow is increased by storm water, so that capacity for storing about eight hours' sewage would be sufficient. This would be at the rate of about 75,000,000 gallons per day. When the sewage is pumped during heavy and long-continued storms at the maximum rate of 112,000,000 gallons per day, some of it, then quite dilute, has to be discharged into less favorable currents. This condition rarely happens, and has not as yet produced any injurious effects. The figures above given indicate that the present reservoir will have sufficient capacity until the ordinary flow of sewage largely exceeds the present volume.

Provision was made in the original design for nearly doubling the capacity of the reservoir when necessary; and all of the works at the outlet have been built with this extension in view. As so enlarged, it will have a capacity for storing for ten hours at the rate of 118,000,000 gallons per day, and for eight hours at the rate of 147,000,000 gallons.

Dorchester Bay Tunnel. — The tunnel under Dorchester Bay has a brick lining, and its section is circular, 7.5 feet in diameter. Its flowing capacity depends upon the difference in level of the surfaces of the sewage in the chambers at its ends. The height of the sewage in the chamber at the lower end varies with the height in the reservoir at Moon Island. Consequently, the flowing capacity of the tunnel will be least when the reservoir is full.

When the reservoir is full and the deposit sewers at the upper end of the tunnel are also full, the sewage at the upper end of the tunnel will be 5.38 feet higher than at the lower end, and under these conditions the tunnel will carry 122,000,000 gallons

per day. If, with the same conditions at the lower end, the sewage in the chamber at the upper end of the tunnel is allowed to rise higher, the carrying capacity of the tunnel will be increased. If allowed to rise to within one foot of the surface of the ground around the chamber, the quantity carried will be 166,000,000 gallons per day. It will be feasible to raise the sewage in this chamber considerably above the top of the deposit sewers, but not to the extreme height above mentioned. Taking into consideration these facts, and that the tunnel would convey larger volumes when the reservoir was not full, the conclusion has been reached that the maximum capacity of the tunnel is 154,000,000 gallons per day, a volume which coincides with that for which the works were designed.*

Pumping Station. — The plant at the present time includes four pumping engines, having a nominal daily capacity of 25,000,000 gallons each. In practice, the nominal capacity of the four engines is exceeded by about 24,000,000 gallons, making the actual pumping capacity about 124,000,000 gallons per day. This amount is so large that very considerable additions to the system can be made without increasing the pumping plant. When further increase is necessary, another engine having an actual capacity of about 32,000,000 gallons can be erected in the present engine house, upon foundations already built, making the total pumping capacity 156,000,000 gallons per day. This is about equal to the maximum capacity of the tunnel, but with no surplus to maintain this capacity while one or more pumps are out of service during repairs. A pumping plant that would at all times have a capacity as great as that of the tunnel was provided for in the original designs, but would require the construction of additional pump wells, foundations, engines and boilers. It will be a long time before these will be needed.

Main Sewer. — The main sewer leading to the pumping station is circular, 10.5 feet in diameter, and has a grade of 1 foot in 2,500. Running full, it has a capacity of 226,000,000 gallons per day. Flowing with a depth of 6.4 feet, it will carry 154,000,000 gallons, the amount adopted as the maximum capacity of the tunnel.

My conclusion with regard to capacity is, that by moderate additions the Main Drainage Works can be made to take care of a maximum of 154,000,000 gallons per day. The more important additions will not be required until far in the future.

* Final report upon the Main Drainage Works of the city of Boston, third edition, 1888, page 35.

The Volume of Sewage to be allowed per Inhabitant.

When no water from rain or melting snow enters the sewers, the flow in them is composed: (*a*) of the sewage proper, which is nearly equivalent to the water supply; (*b*) of soil water entering the sewers from the ground through leaks, or purposely admitted for the drainage of cellars and wet ground; (*c*) sea water leaking into the sewers, or purposely turned into them after being used for manufacturing purposes; (*d*) water used for flushing the sewers.

The volume flowing in sewers when no storm water enters them has commonly been estimated in the past to be little in excess of the amount of the water supply. The experience with the Boston Main Drainage Works, and with many systems of pipe sewers from which storm water has been excluded during the past two or three years, has shown that the soil water is a much more important element than previously supposed.

The population served by the Main Drainage Works in 1887 was 274,000. The minimum daily amount pumped during this year is given in the city engineer's report as 27,796,176 gallons, equal to 101 gallons per inhabitant. The average daily amount pumped, including storm water, is given as 43,630,657 gallons, equal to 159 gallons per inhabitant. These estimates were based upon pump measurements. To get the actual volume pumped, it is necessary to make some deduction for the slip of the pumps. This has been found to be variable, and sometimes very large, on account of the destruction of a rubber valve or for some other cause; and it is, consequently, more satisfactory to base estimates of the volume of sewage upon 42 measurements of the daily flow in January, February and March, 1887, made in the Moon Island reservoir. It is fortunate for our purposes that these measurements were made at a time of year when a large flow in the sewers may be expected, on account of the waste of water to prevent freezing in January and February, and because the soil water would be higher than the average in March. It is not to be expected, however, that so few observations would include the maximum flow which might occur during extremely cold weather, like that of January, 1888; or the effect of the unusual height of ground water which now exists (December, 1888), owing to the exceptionally heavy rainfall of the past few months.

On 12, or 29 per cent., of the 42 days mentioned, the flow was affected by storms, and the volume of sewage varied from 152 to 326 gallons per day per inhabitant in the district sewered. One storm, probably snow, did not affect the flow. On 18 other days,

or 43 per cent. of the whole, the daily flow per inhabitant was greater than 138 gallons, reaching a maximum of 200 gallons. This included some days when water from melting snow ran into the sewers. On the remaining 12 days, or 29 per cent. of the whole, the flow was less than 138 gallons per inhabitant, the lowest record being 100 gallons and the next lowest 118 gallons.

Out of the 42 days, 18 can be selected when it is known that no water entered the sewers from storms, melting snow or flushing. On these days the volumes ranged from 100 to 147 gallons per inhabitant, averaging 132 gallons.

To apply these results obtained on the Boston Main Drainage Works to extensions of the system into the suburban districts, or to other sewerage systems, it is desirable to know the proportion in which sewage proper, ground and sea water contribute to make up the maximum volume given in the preceding paragraph.

During these three months in 1887, the average daily consumption of water in the part of Boston supplied by the Cochituate Works was 83 gallons per inhabitant. The district connected with the Main Drainage Works uses somewhat more than the average amount of water consumed, and the weather at the time of the maximum flow was cold, so that the water supply in the district at this time may be called 90 gallons per person. The sewage proper is assumed to equal the water supply. This does not take into account the water which for various reasons may not find its way into the sewers; nor, on the other hand, the water supplied from Jamaica Pond or from private sources, such as the wells of breweries and manufacturing establishments.

The amount of sea water entering the sewers has been estimated from many determinations of the amount of chlorine, made in May, 1885, by the late Prof. Wm. Ripley Nichols. The mean result found was that 11.5 per cent. of the volume flowing at that time was sea water, equal to 3,300,000 gallons per day. As there is no reason to think that the quantity of sea water entering the sewers has changed, this volume is assumed as the amount in 1887. It is equivalent to 12 gallons per day per inhabitant. Of this sea water, 1,000,000 gallons per day, equal to nearly 4 gallons per inhabitant, comes from a sugar refinery in South Boston, and as it is not polluted it should be excluded from the sewers. The remainder is mostly leakage into the old sewers near the water front.

Subtracting the sewage and sea water from the total, there remains 45 gallons per inhabitant per day to be classed as ground water, which may be subdivided into that leaking into the sewers and house connections, that coming from the drainage of cellars

and low lands, and that allowed to come freely into such sewers as have been built to take the place of brooks. Some of this ground water could be kept separate from the sewage and discharged by independent channels into the harbor, relieving the main system to some extent.

Collecting the above subdivisions of the maximum daily flow, the following table is obtained: —

Sewage proper, equal to water supply, . . .		90	gallons.
Sea water, { leakage, ...	8		
Sea water, { from sugar refinery, . . .	4		
	—	12	"
Ground water, ...		45	"
Total, ...		147	"

All the foregoing statements refer to the average rate of flow during the whole day.

As the larger part of the water supply is used in the day time, the flow of sewage at this time is correspondingly increased. This increase during some hours of the day is estimated to be at the rate of 30 gallons per day per inhabitant, which, added to 147 gallons, makes the maximum rate of sewage flow, when no storm water enters the sewers, and excepting extraordinary occasions, 177 gallons per inhabitant.

The twenty-eighth day of January, 1888, being an extremely cold day at the end of a very cold week, furnishes an instance when the volume of sewage was greater than the maximum above given. This case will be referred to in detail, because of its value in designing sewers from which storm water is excluded, rather than for its value in connection with the capacity of the Main Drainage Works, where the provision made for storm water is sufficient to take care of the sewage flow at a time like this, when it is evident that no storm water could enter the sewers.

The volume of sewage by pump measurement on this day was 186 gallons, or, with 5 per cent. allowance for slip of pumps, 177 gallons per inhabitant. As the pump measurement was not considered wholly trustworthy, the records of the water department were obtained, which showed that the amount of water consumed on this day was 151 gallons per inhabitant. It would require but 26 gallons of ground and sea water, in addition to the water supply, to make up the 177 gallons deduced from the pump measurement, so that it seems fair to assume that on this occasion the latter measurement was substantially correct. Other records of the water department, giving the pressures in the pipes in the city

at different hours of the day, furnished a means for determining approximately the quantity of water being consumed at these times. On account of the great waste of water at night to prevent pipes from freezing, the rate of flow was unusually uniform; yet there were about six hours when the consumption of water was at the rate of about 19 gallons per day above the average for the whole day, from which it may be inferred that the maximum rate of sewage flow during a part of the day was at the rate of 196 gallons per inhabitant.

The amount of water consumed in many cities and towns on the day above mentioned is reported to have exceeded any previous records. In answer to inquiries made at the time, returns were received from which the following table has been deduced: —

CITY OR TOWN.	Average Daily Consumption per Inhabitant.	Maximum Daily Consumption per Inhabitant in January, 1888.
Boston, Mass. (Cochituate and Mystic Works),	79	151
New Bedford, Mass.,	85	150
Brookline, Mass.,	71	100
Providence, R. I.,	39.5	54
Waltham, Mass.,	39	50
Newton, Mass.,	31.3	50
Taunton, Mass.,	31	43

The table shows a remarkable difference in the amount of water wasted in different places to prevent freezing of water pipes, and is instructive as to the volumes to be provided for in designing sewers.

But few sewer gaugings have been made to determine the mean or maximum rate of flow in sewers when not affected by storm water. Such as are available and may furnish information in designing sewers for the Mystic and Charles River valleys will be referred to.

In St. Louis, gaugings of the Compton Avenue sewer were made every hour for several days in March, 1880. The maximum flow was at the rate of 202 gallons per day for each of the 8,200 inhabitants in the district sewered. Every night the rate of flow diminished to about 90 gallons per inhabitant, which probably consisted of ground water and waste from the water supply.

Very complete gaugings of the volumes flowing in the sewers in Providence, R. I., taken in 1884 by Samuel M. Gray, city engineer, showed that the maximum flow in different sewers varied from 39 to 408 gallons per day per person connected with them.

From this very great variation, it is evident that the result obtained from any one sewer has little value to those not familiar with the causes of the variation.

The report containing these gaugings gives an estimate based upon them of the total daily dry-weather flow of town sewage as 3,000,000 gallons per day, 36,421 inhabitants being connected with the sewers. The volume per inhabitant is consequently 82.4 gallons per day. The average daily amount of water supplied by the Providence water works during this year was 35 gallons to each inhabitant in the whole city. From these results it may be inferred that the amount of ground and sea water which found its way into the sewers was in the neighborhood of 47 gallons per inhabitant.

To obtain further information as to the amount of ground water finding its way into systems of sewers from which storm water is excluded, a circular was sent in January, 1888, to those in charge of all known systems of this kind in the United States. Many replies were received, but in most cases no measurements had been made from which exact information could be furnished. The general statement was made in several instances that there was considerable ground water which had not been measured. The definite information received is as follows: —

KALAMAZOO, MICH. — "Some ground water finds its way into the system, estimated, from data taken before the sewers were open for public use, to be 20 per cent. of the capacity of the mains."

NORFOLK, VA. — "No accurate estimate made, but ground water forms at least 60 per cent. of pumping." From information given elsewhere in the returns, the maximum flow is found to be about 167 gallons daily per inhabitant connected with the sewers. Of this, the ground water, estimated at 60 per cent., equals 100 gallons.

SCHENECTADY, N. Y. — "The sewers are laid through wet ground and quicksand in some instances. The Erie Canal seepage also affects them in a small degree. Measurements made at about the time the system was completed indicate that the infiltration of ground water amounts to about 5 per cent. of the capacity of the mains."

I have recently examined two new systems of pipe sewers which were built with the intention of excluding ground water, and in both cases the amount of such water collected by the sewers was considerable. In one of these cases, where the population connected with the sewers is small, the amount of ground water will probably exceed that of the sewage proper.

To determine the quantity of sewage which will reach the Boston Main Drainage Works, should a large amount of suburban territory be connected with them, requires a consideration of the

following points: Sewers built in extending these works in the future will as a rule be more nearly water-tight than those built in the past; but, as these sewers will be in less populous districts, the amount of leakage per inhabitant may be even greater than now, unless some radical change is made in the methods of construction so as to make the sewers water-tight, or the soil water is removed by independent drainage pipes.

Keeping the sewage separate from the storm water in the districts not now provided with sewerage systems will permit a much larger territory to be connected with these works.

The amount of water consumed in the suburbs is much less than in the city, and will probably continue to be so in the future, owing to the smaller amount used for manufacturing and business purposes, and because of the number of inhabitants who go to the city in the day time.

The average daily consumption of water per inhabitant in Boston, and in some of the suburban cities and towns to be considered in connection with the Boston Main Drainage Works, is stated in the following table: —

CITY OR TOWN.	Average Daily Consumption of Water per Inhabitant in 1887.
Boston (Cochituate Works),	81 gallons.
Brookline,	70 "
Newton,	31 "
Waltham,	34 "
Cambridge,	62 "

Having in view the foregoing facts and statements, the daily allowance of sewage, exclusive of storm water, in the city districts where the consumption of water is large and the sewers are built to receive surface water, is estimated to be 117 gallons per inhabitant during seasons of low flow, and 132 gallons during seasons of high flow, such as are produced by cold weather, or at times when there is much water in the ground. During the parts of a day when the most water is used, the rate of flow is estimated to be 30 gallons more than the figures given.

For the suburban districts, where less water is consumed and where it is proposed to exclude surface water, the corresponding figures are estimated to be 85 and 110 gallons, with an additional rate of 25 gallons per inhabitant during parts of the day.

The amounts of sewage in the two cases above given are not strictly applicable to some of the suburban districts, where an

intermediate condition exists; but, by judiciously grouping portions of these districts with one of these classes, and the remainder with the other, a sufficiently accurate estimate may be made.

The report of the Massachusetts Drainage Commission proposed that sewage from Hyde Park, Dedham, Brookline, Newton, Waltham and Watertown, the larger parts of Cambridge and Somerville, and the whole of the Brighton and Charlestown districts of Boston, should be disposed of by the Boston Main Drainage Works.

The population in 1885 of the district which would be tributary to the Main Drainage Works, if all of these places were connected with them, was 504,000. From estimates of the future population of this district, together with the amounts of sewage to be allowed per inhabitant, as above given, it is found that the dry-weather flow of sewage will be increased in 1906 by about the same amount as the capacity of the works when developed; so that the volume of storm water they will take will then be about the same as now. As a large part of the territory to be added admits storm water to the sewers, the overflows would operate with much less rainfall than at present, and at or soon after 1906 some further relief would be needed.

The time between the completion of the works and this date would be so short as to make it undesirable to add the whole territory mentioned, if some other provision can be made for a portion of it.

The investigations made under your direction have shown that Cambridge, Somerville and Charlestown can be provided for by the North Metropolitan Sewerage System until 1930 at a reasonable cost. It is very desirable to connect the remaining cities and towns (excepting possibly Dedham, which may be taken care of by itself) with the Boston Main Drainage Works, if they have sufficient capacity.

The population connected with the Boston Main Drainage Works in 1888 is estimated to be 293,000.

The estimated population in 1930 of the territory in Boston which it is feasible to connect with these works is 546,000, and of the suburban district, comprising Hyde Park, Dedham, Brookline, Newton, Waltham and Watertown, 160,000; in all, 706,000.

Using these estimates of population, and the estimates before given of the volume of sewage per inhabitant and of the capacity of the works, the table given below has been prepared, showing the total amounts of sewage under different conditions, and the corresponding amounts of storm water which can be taken care of.

In this table no allowance is made for the temporary increase in the capacity of the works due to the storage of the sewage in the sewers.

PRESENT CONDITION — 1888.

	Average Flow for 24 Hours		Maximum Rate of Flow During Part of the Day.	
	Seasons of low flow.	Seasons of high flow.	Seasons of low flow.	Seasons of high flow.
Maximum capacity of works,	112,000,000	112,000,000	112,000,000	112,000,000
Volume of sewage, . . .	34,000,000	39,000,000	43,000,000	47,000,000
Capacity for storm water, .	78,000,000	73,000,000	69,000,000	65,000,000

FUTURE CONDITION — 1930.

Maximum capacity of works,	154,000,000	154,000,000	154,000,000	154,000,000
Volume of sewage, . . .	77,000,000	90,000,000	98,000,000	110,000,000
Capacity for storm water, .	77,000,000	64,000,000	56,000,000	44,000,000

The first column of the table shows the average condition which will exist during the larger part of the year; and it will be observed that the capacity for storm water in 1930, with this smaller district added to the works, will be substantially the same as at the present time. The second column, which represents the condition which will exist during a smaller part of the year, shows a moderate reduction in the storm water capacity. The further reduction indicated in columns three and four are less important than they may appear, as they apply only to the high sewage-flow in the daytime, and are offset in part by the correspondingly greater capacity for storm water during the hours of low flow at night.

From these results the conclusion is reached that the Main Drainage Works, when developed as before indicated, without the construction of the "high-level" sewer, will have sufficient capacity to dispose of the sewage of Hyde Park, Dedham, Brookline, Newton, Waltham and Watertown, and the portions of Boston which can be served by it, until 1930.

THE PRESENT OPERATION OF THE MAIN DRAINAGE WORKS, WITH REFERENCE TO THE OUTLET.

The following report is based chiefly upon personal observations during the first two and a half years of the operation of the works.

The discharge of sewage from the reservoir at Moon Island is begun either one or one and a half hours after high tide, when the outward current past the outlet is well established. About

15,000,000 gallons of sewage are discharged in about 40 minutes. As the sewage is lighter than the sea water, it rises toward the surface soon after being discharged, and spreads out until it has a depth of less than a foot. Half an hour from the beginning of the discharge the sewage covers an area about half a mile in diameter. In this condition the sewage, already considerably diluted, moves outward with the current, and further dilution takes place, the process going on most rapidly at the bottom of the layer of sewage. Up to a certain stage in the progress of this dilution, the surface of the sewage contains enough greasy matter to prevent waves, except when the wind blows very hard. When the dilution of the sewage has progressed so far that waves begin to form and its specific gravity has approached that of sea water, it rapidly becomes mixed with water from greater depths, and very soon cannot be distinguished by the eye or nose from unpolluted sea water. The last change here described usually takes place in less than an hour and a half after the sewage is discharged, and at a distance from the outlet not exceeding two miles.

In the above statements reference is made to the sewage as it is indicated by the discoloration of the water, neglecting the suspended particles, most of them heavier than either sewage or salt water. Their presence in the sewage is made apparent by deposits which form upon the bottom of the reservoir to a depth of about one-quarter of an inch each time the reservoir is filled, and by deposits which form to a greater depth in the small cove situated between the outlet pier and Moon Island, and sheltered from all currents. Some examinations were made, to ascertain if deposits had taken place elsewhere than in the cove above mentioned. When the works had been in operation about a year, I examined at low tide the shores of Long Island, where deposits were most likely to gather, but could not find any. The next year an examination was made by my direction of the shores of several islands near the path of the sewage, also of the southerly shore of Moon Island and of the bar leading from it to Squantum. No deposits were found that appeared to have come from sewage, with the exception of a few grease balls.

On the north-easterly side of Moon Island, near the outlet, are some flats below the level of ordinary low tide, over which the sewage flows at each discharge. One day, when these flats were uncovered by an extremely low tide, they were examined and very little sewage deposit was found. With so little deposit upon flats over which so much sewage had passed, it seems probable that no deposit takes place in the channels where the currents are stronger.

On one occasion bottles were filled every 15 minutes from the area of sewage going outward with the current. These bottles were kept in an office for a long time, and those taken one hour or more after the beginning of the discharge never showed by their appearance or odor that they contained any sewage.

The Methods by which each City or Town in the North Metropolitan Sewerage District may provide for itself a System of Sewerage with its Outlet into the Main System.

The third section of chapter 95 of the Resolves of 1887 requires the State Board of Health "to define the methods by which said cities and towns, or parts of any city or town, may utilize the trunk line and main branches as an outlet of a system of sewerage and drainage for said respective cities and towns, and parts of cities and towns, and to show the same by plans and maps."

The fourth section of the Resolve requires "such surveys and levels to be made in said cities and towns and parts of cities and towns as will enable said Board to determine with accuracy the methods by which said cities and towns and parts of cities and towns may respectively utilize said trunk line and main branches; and to report such methods by plans showing the main lines by which each may so provide for itself a system of sewerage and drainage with its outlet into said trunk line or main branches."

In carrying out the duties required by this Resolve, the first thing done was to obtain copies of the best existing plans of each of the cities and towns in the district. On these were put all existing information which could be gathered as to the elevation of the streets, and other features of importance in designing a system of sewers.

The Resolve of the Legislature authorizing this work requires only that the main lines in each city or town and their connections with the main system shall be determined, and shown by plans and maps; but, to make accurate plans of the main lines, it is obviously necessary to know the area of the contributing district, its population, and the total length of its streets. This made it necessary to determine the general features of the whole sewerage system for the city or town.

To do this, each city or town not now provided with sewers was reconnoitred, and the direction in which sewers should run in each street was indicated upon the plans, as well as the outline of the different sewerage districts. Where the existing information was insufficient to determine the general features of the sewerage system, additional levels were taken.

The lines of main sewers shown upon these preliminary plans were measured and levels were taken along them, except where on account of previous information this work was unnecessary; and large scale profiles were made, on which were drawn main sewers of the proper size and grade, and their connections with a sewer of the main system. Finally, tracings of the sewerage plans of each city or town, and of the profiles reduced to a small scale, were prepared in such a way that photographic copies of them could be made.

The system shown as thus indicated for each city or town is that which from all available information appeared to be the best one to adopt. In some cases, however, the sewers can be arranged in several ways with almost equally good results, and the plan to be selected will depend upon local conditions, such as the growth of population in certain localities and the construction of new streets. When sewerage is to be provided for only a part of the districts in a town, it may be desirable to extend the limits of those districts in which sewers are to be built so as to include thickly settled areas beyond their borders.

In deciding which were the main sewers of the towns, those required to drain distant low districts have been included, as well as the larger sewers connected with the Metropolitan system.

The main features of the sewerage system of the several cities and towns will now be described. The details are shown upon the plans now deposited in the office of the Board.

Stoneham. — The Metropolitan system furnishes two outlets for the sewage of this town. The principal one, which by the construction of a system of sewers in the town can be made to serve nearly the whole of the thickly settled portion, is located at the town line between Stoneham and Woburn, near Montvale Avenue. The other outlet is in South Street, at the town line between Stoneham and Melrose, and provides for the village of Haywardville and the large territory tributary to Spot Pond, now sparsely settled, but which may in the future require sewers. The construction of a system of sewers within the town to connect with these outlets presents no special difficulties.

Woburn. — The sewer already built by the city of Boston to take the drainage from the tanneries will be included in the Metropolitan system as far up as the boundary line between Woburn and Winchester. This sewer will furnish an outlet for the larger part of the central village. To serve the lower portions of this village and Cummingsville, an outlet at a lower level is provided at the town line near the outlet of Horn Pond.

East Woburn and the territory in the northerly part of the town can find an outlet into the sewer running from Stoneham through East Woburn to Winchester. The sewage of North Woburn can be taken by a main sewer in the valley of the Abbajona River to East Woburn, a method which would provide for the growth of the former village into lower territory and for any future population of the valley below. As, however, sewerage facilities may be required for this village before it is considered desirable to build so much main sewer through a district containing so few inhabitants, another line has been surveyed, taking the sewage into the sewer draining the lower portions of Woburn Centre; and this low-level sewer has been designed large enough to take the sewage from North Woburn.

Winchester — The sewer built by the city of Boston through this town has been adopted as a part of the main sewer of the Metropolitan system, and a branch of this system runs nearly parallel with the Abbajona River from the main to East Woburn, so that many opportunities are furnished for connecting the sewers of Winchester with the main system. Eight connections with the main are shown on the plans prepared for the sewerage of the town.

Medford. — The main sewer of the Metropolitan system in this town lies north of the Mystic River. It extends from Winchester to Everett, and in its course passes through the villages of West Medford, Medford Centre and Wellington. In the village of West Medford it is joined by the Alewife Brook branch. These sewers furnish a favorable outlet for all town sewers north of the river, except in the westerly part of West Medford, where there is a small district near the river which these sewers are too high to accommodate. For this district a suitable outlet is provided on the northerly side of the river by means of a low-level sewer, to be built across the river to the pumping station on the Alewife Brook branch.

For the district on the southerly side of the river two outlets are provided. One of these is located in Mystic Avenue at the Somerville line, where the bottom of the sewer is nearly at the level of low tide. With a main town sewer built in Mystic Avenue, South and West streets, with the proper grades, this outlet will provide for the sewage of the whole district north-east of the Lowell Railroad. Sewage from the higher territory on the opposite side of the railroad is to be carried in a north-westerly direction to a branch of the main system, ending in Boston Avenue at the Somerville line. The sewage from this higher district will reach the main sewer of the Metropolitan system by gravity,

while that from the district before mentioned will join the sewage from Cambridge, Somerville and Charlestown, and be pumped to the main sewer.

Belmont. — The main outlet for this town will be furnished by a branch of the main system, ending at the town line between Belmont and Cambridge, south of the Fitchburg Railroad. This branch will take the sewage from the whole town, except a small district in the south-easterly corner near the Watertown line. This district can be sewered in connection with the adjoining portions of Cambridge, either by the system of city sewers, now partly constructed, which would empty into the intercepting sewer near Charles River, or by a sewer around the westerly and northerly sides of Fresh Pond to the head of the Alewife Brook branch of the main system.

Arlington. — Three short branches, to be built from the Alewife Brook branch across the brook into Arlington, provide outlets for the sewage of this town. One of these outlets is located in Decatur Street, a second in Charlestown Street, and the third on private land north of the Arlington Branch Railroad. The principal sewer of the town has been designed to enter the second outlet, the other outlets being provided for the main sewers of the lower districts near Mystic River and Spy Pond.

There are no engineering difficulties to prevent the principal sewer from being carried to either of the outlets last mentioned, and local conditions when the sewers are built may make it desirable to modify the plans in this respect.

Cambridge. — This city now has a system of sewers discharging either into Charles River or Alewife Brook. It is proposed to intercept these sewers near their outlets in all but a few cases, to be referred to, where the intercepting sewer is necessarily located at a considerable distance from the river. The main sewer used jointly by Somerville and Cambridge, and having an outlet at Craigie's bridge, is first intercepted where it crosses the Metropolitan sewer. It is proposed to intercept it again at the line between Somerville and Cambridge. The territory below this point is provided with an independent system of sewers at a higher level, which receives all the local sewage, so that further interception of the lower main sewer is unnecessary. The sewage in the higher system is to be intercepted at the corner of Bridge and Cambridge streets, and carried back by a sewer in Bridge, Winter, Fifth and Gore streets to the Metropolitan sewer at the corner of Medford and Warren streets. It is a branch from this sewer at the corner of Winter and Fifth streets which will inter-

cept the Somerville and Cambridge sewer at the city line, as above mentioned.

Sewage from the large territory now finding an outlet through the Binney Street sewer is to be intercepted at the corner of Binney and Ninth streets, and carried to the Metropolitan sewer in Portland Street. There is quite a large territory between Ninth Street and the river, which it was formerly intended to drain into the large Binney Street sewer below the point where the sewage is intercepted; but, as this would in the future permit a large quantity of sewage to go into Charles River, a system of sewers should be adopted for this district to bring the sewage back to Ninth Street. The storm water can go into the Binney Street sewer.

Somerville. — Three sewers of the Metropolitan system pass through this city: one from Cambridge to Charlestown *via* Medford and Poplar streets, private land, Washington and Cambridge streets; another from Medford to Charlestown most of the way in Mystic Avenue, and the third from Cambridge along Alewife Brook to Medford. Most of Somerville is laid out into sewerage districts, in which many sewers have already been built. The method of intercepting the Somerville Avenue sewer has already been described in connection with Cambridge. Other existing sewers will be intercepted where they cross the main system. A convenient outlet is provided by this system for all districts not now sewered.

Charlestown. — The sewers of the Metropolitan system run through the marginal streets of this district, and will intercept all city sewers. To prevent all sewage from entering the harbor, new sewers connecting with the intercepting sewers will be required from the State Prison, navy yard, and a few small marginal areas.

Melrose. — A branch of the Metropolitan system enters this town at the Malden line, a short distance east of the Boston and Maine Railroad, and runs parallel with the railroad to Wyoming Avenue, thence westerly in this avenue to the Stoneham line. All of the sewage from the thickly settled parts of the town can be brought into this branch, the main sewer of the town connecting with it in Wyoming Avenue just east of the railroad.

In the south-easterly corner of the town there is quite a large territory, now containing very few inhabitants, which naturally drains through Malden to the Pines River. Should sewers be required for this territory, they will have to follow the natural direction of the drainage to Malden, where it will be feasible to connect them with city sewers tributary to the Metropolitan system.

North of this territory is a still larger one along the easterly

side of the town, which naturally drains towards the Saugus River, and now contains only a few scattered houses. From some parts of this district, where growth of population now seems most likely to take place, it will be feasible to divert sewage into the Metropolitan system by means of sewers crossing low points in the boundary between the Mystic and Saugus water-sheds. If sewers should ever be required for the remainder of the district, the sewage could not be brought into the Metropolitan system.

Malden. — One branch of the Metropolitan system enters this city from Everett at Green Street, and extends in a northerly direction, passing through Middlesex and Pleasant streets and Linden Avenue in the central portions of the city, to the Melrose line a short distance east of the Boston and Maine Railroad. A second branch ends in Pearl Street at the Medford line, and will furnish an outlet for the sewage of Edgeworth, and for the territory west of Malden River and the Boston and Maine Railroad, nearly up to the Oak Grove station.

The most difficult part of the city to provide for is the village of Linden, on account of its low level and remoteness from a pumping station. To bring its sewage into the main system, it is necessary to construct from this village a main city sewer with an unusually light grade and in a rather deep cutting, generally parallel with the Saugus Branch Railroad, to the branch sewer first mentioned, or to pump the sewage so that better grades may be obtained and the depth of cuttings be reduced. A comparison of the velocities obtainable in the sewer having the lighter grade with those which are found to give good results in practice, shows that this sewer could be made to operate in a satisfactory manner, if carefully constructed, and given an unusual amount of attention when in operation to keep it flushed and clean. As the amount of attention would be very much less than that required to operate a pumping station, not to mention the cost of fuel, and as the first cost of a pumping station would probably more than offset all that could be gained by constructing sewers at a less depth, it seemed obvious that the scheme which did not require the pumping station was by far the better one to adopt. This sewer and the branches of the main system will provide convenient outlets for all portions of the city not yet mentioned.

Everett. — The main sewer of the Metropolitan system passing through this town from Medford to Chelsea, and the branches to Malden and Charlestown, furnish convenient outlets for sewers in all parts of this town, with the exception of two districts in the northerly portion. One of these districts, located on both sides of Ferry Street, north-west of Broadway, drains naturally towards

Malden, and can be sewered through the Malden sewers to a branch of the main system. The other district slopes towards the Pines River, and cannot be brought into the main system. The latter district has an area of 240 acres, mostly occupied by the Woodlawn Cemetery, and contains few inhabitants.

Chelsea. — The main sewer of the Metropolitan system extends from the Everett line through Second, Winnisimmet, Williams and Marginal streets to Eastern Avenue, where it turns and crosses Chelsea River to a pumping station in East Boston. A branch is located in Eastern Avenue from Willowby Street to the main at Marginal Street. These sewers will intercept all districts now sewered excepting the Prattville district, a small district extending from Beacon Street along Broadway to an outlet at Chelsea bridge, and a small portion of the Spruce Street district west of Second Street. It will be feasible to connect these districts and all others not now sewered with the main system.

East Boston and Breed's Island. — A main branch and several subsidiary branches of the Metropolitan system discharging into the main sewer at the pumping station will intercept all of the city sewers in East Boston south-west of Swift Street, excepting a pipe sewer a few hundred feet in length in Putnam Street. Ample provision is made for the very small portion of this territory not now sewered, and for land which may be made by filling marshes and flats. Breed's Island and the portions of East Boston north-east of Swift Street now have no sewers except in Moore Street and a street crossing it. In the whole of this territory it is proposed to exclude storm water from the sewers The main sewer in this vicinity, carrying the sewage after being lifted at the East Boston pumping station, is at a higher level than in most places, but it is low enough to take sewage from nearly all of the uplands. To provide for land already made or which may be made by filling upon the marshes, and for some uplands, mostly in the Moore Street district, a sewer leading back to the pumping station will be required. In this way provision can be made for all parts of this territory without an independent pumping station.

Winthrop. — The main sewer crosses Belle Isle inlet into Winthrop a short distance south of the Boston, Winthrop and Shore Railroad, and runs in an easterly and south-easterly direction, passing through the junction of Winthrop, Main and Revere streets, and across marshes to Shirley Street near Pearl Avenue; thence through Shirley Street to the end of Point Shirley. At the upper end its bottom is about one foot and at the lower end about six feet below low water.

The sewage of Winthrop Highlands can be brought to the main system by two main town sewers, one on the easterly side passing through Beach Road and Shirley Street, and the other on the westerly side crossing the marsh. The sewage from Winthrop village can be brought to the main at Pleasant Street, Winthrop Street, and the extension of Buchanan Street The larger part of this village will be served by the Pleasant Street sewer, which it is proposed to extend by the most favorable route, much of the way near the railroad, to the southerly part of the village. It is feasible to provide for all parts of this village, excepting a very small area at the corner of Somerset and Johnson avenues. The remaining portions of the town are near the main sewer, and can be connected with it without difficulty.

Independent Systems of Sewerage for the Cities and Towns in the North Metropolitan Sewerage District.

The eighth section of chapter 95 of the Resolves of 1887 requires the State Board of Health to consider and report "whether any city or town within such district can more advantageously provide for itself a system of sewerage and drainage by itself, and not as a part of said general system."

There are three ways of disposing of sewage which may prove applicable to some of the cities and towns in this district: —

1. The discharge of crude sewage into bodies of water where it will be sufficiently diluted to prevent offence.

2. The removal of the suspended particles by chemical precipitation, and the subsequent discharge of the clarified effluent into water.

3. The filtration of the sewage through land, thereby partly or wholly purifying it.

Winthrop and East Boston are so situated that they should be considered in connection with the first method of disposal.

The situation of the other cities and towns is such that their sewage cannot be discharged into adjacent waters without contributing to the pollution which a general system is intended to relieve.

Mr. C. H. Swan, C. E., has made for your Board investigations of the second method, as applied to the cities and towns of the Mystic valley collectively, which have shown it to be much more costly than the general system for disposing of the sewage at the Deer Island outlet recommended by you. It would cost as much or more to provide independent systems by this method for the

different municipalities, so that on this ground, regardless of other considerations, it does not appear that any city or town can more advantageously provide for itself by this method a system of sewerage.

To apply the third method requires that a sufficient area of suitable land for filtering the sewage shall be available at a reasonable cost, and that its preparation for use shall not require too large an outlay. Preliminary investigations show that it would be more costly for the smaller towns, such as Winchester, Arlington and Belmont, to pump their sewage to land than to join the general system. In these towns no suitable land was found that could be reached by gravity. In Medford, the cost of pumping, together with the high cost of any land that might be available, make this method of disposal undesirable. In the cities and towns nearer Boston no available land could be found. In Stoneham and Woburn some land was found sufficiently available to make it desirable to consider these places more fully.

These general considerations indicate that the only places in the North Metropolitan Sewerage District which require special consideration as regards an independent system of sewerage are Stoneham, Woburn, East Boston and Winthrop. The case of Revere, which is outside of this district but which might be connected with it, will also be referred to.

Stoneham. — The present population of the town is about 6,000. Nearly all of the inhabitants who will need sewerage for a long time live in the territory which drains towards Woburn, and only this territory will be considered. It is estimated that not less than forty-five acres of such land as can be reached by gravity will be required for filtering the sewage. Only a small amount of suitable land is situated low enough to receive the sewage from the whole territory; but additional land at a higher level can be had, to which sewage from the main village and the higher parts of the territory can be diverted.

The land selected was the best in Stoneham for filtration; but both in material and topography it did not appear from surface indications to be very well adapted to this use. In the absence of examinations by test pits, the amount of sewage which can be purified per acre cannot be stated definitely. For the purpose of ascertaining approximately the cost to the town of this method of disposal, as compared with the cost of joining the general system, it has been assumed that the amount of land required at present would be, as before stated, forty-five acres.

Estimates were made of the cost of intercepting the sewage from the higher districts, of purchasing enough land to make a

reasonable provision for the future, of preparing forty-five acres, and of all other work incidental to this system; also, of the cost of operating. These estimates indicated that this system, if wholly successful, would probably be cheaper for Stoneham than to join the general system. When, however, the disadvantages of establishing a sewage field near and upon land now used to some extent for building purposes, the trouble that may arise from turning insufficiently purified sewage into a stream used lower down as a water supply, and the uncertainty as to the successful purification of sewage upon land of this character, are taken into account, I am of the opinion that Stoneham would gain nothing by the adoption of an independent system.

Another scheme was considered for disposing of Stoneham sewage upon land on the easterly side of the village of East Woburn. This land is naturally more favorable for filtration than that in Stoneham, and not more than half as many acres would be required. The cost of preparation per acre would be less, and the chance of purifying the sewage successfully would be greater.

The total cost of works in this case would be less than in the other, but this feature in favor of the scheme would be offset by the disadvantages of a location in another town, and in a part of a village now laid out into streets and built upon to some extent. The objectionable feature of discharging the effluent into a stream used for water supply would remain as in the other case, though to a less degree.

Woburn. — No available land could be found in Woburn or below it on which the sewage could be discharged by gravity; but, as this city has a population of 12,000 or more, pumping may not make an independent scheme too costly, and a scheme was investigated by which the sewage was to be collected on the easterly side of Horn Pond and pumped through a force main about two miles long to a level tract of gravelly land north of the village of East Woburn, containing about seventy acres, and bounded by Salem, Pine and Central streets and the Abbajona River. The cost to Woburn of this scheme would be about the same as the cost of joining the general system. Under these conditions the latter plan is obviously the better one to adopt.

East Boston. — This community is more favorably situated than any other large one in the North Metropolitan Sewerage District for discharging its sewage in a crude state into the harbor; and a plan for doing this by a single outlet into the current on the southerly side of Bird Island flats was recommended by the Massachusetts Drainage Commission. As stated by the chief

engineer of that commission, this method of disposing of the amount of sewage furnished by East Boston probably never would cause a serious nuisance; but, as the sewage discharged during the early part of the flood tide would go up the harbor along the East Boston docks and into the estuaries, which it is proposed to keep free from sewage, it may properly be urged that East Boston should not be allowed to put sewage into these waters while other communities are prevented from doing so.

The objections to connecting East Boston with the Metropolitan system now proposed, which provides a main sewer in East Boston, are very much less than they were to connecting it with the main system proposed by that commission, which would require an independent pumping station, a siphon across Chelsea River, and the subsequent filtration of the sewage at the Saugus marshes.

The estimated cost of the independent system for East Boston, proposed by that commission, is more than that of a system of intercepting sewers for East Boston, and the cost of enlarging the main sewer and other works of the Metropolitan system between East Boston and the Deer Island outlet to the extent required to carry the additional sewage; moreover, the cost of operating an independent system of works would be much more than East Boston's share of the cost of operating the general system. The Metropolitan system provides for the whole of East Boston and Breed's Island, while the independent system did not provide for the territory north-east of Swift Street in East Boston, or for Breed's Island. The relative cost to Boston of providing for East Boston's sewage by the general or an independent system depends upon the method to be adopted for apportioning the cost of the former; but, even if the cost of joining the general system should be much greater, I am of the opinion that this course should be adopted.

Winthrop. — This town is now proposing to construct a system of sewers to accommodate the population along its beaches, provision being made for extending this system to other parts of the town. As it is proposed to discharge the sewage by gravity, at least for several years, the annual cost of operating this system would be small, so that it might be cheaper for the town not to join the general system. Taking into account, however, the better grades to be obtained with a general system, the more favorable outlet, and the fact that pumping will probably be required in the future to dispose of the town's sewage, it will probably be better for the town to join the general system. A definite opinion upon this point cannot well be given until the method of apportioning the cost to the different towns is determined.

Revere. — An outlet for the sewage of this town can be provided by a branch of the main system passing through Chelsea and entering Revere just north of the main line of the Eastern Division of the Boston and Maine Railroad. It is feasible to bring the sewage of nearly the whole town to this outlet, though the sewers for this purpose would have light grades, and be expensive to build. Whether it would be better for the town to join the system in this way, or to dispose of its sewage independently, would require a careful consideration, based upon surveys and estimates of cost of other schemes of disposal. As this town can hardly be considered in the Mystic valley, its case has not been sufficiently investigated to warrant an opinion as to whether it would be for its interests to join the general system or not.

Estimated Cost of Sewerage Systems for the North Metropolitan and Mystic Valley Districts.*

By your direction, estimates of cost of the various schemes of sewerage for the North Metropolitan and Mystic valley sewerage districts have been submitted to your consulting engineer, Mr. J. P. Davis, and myself, for review.

Mr. Carson furnished estimates of the cost of sewers and their appurtenances for all schemes, with profiles of the lines, showing the materials as indicated by borings, and the cost of pumping stations for all except the precipitation scheme. Mr. Swan had previously reported estimates of cost of this pumping station, and of all works beyond it connected with the precipitation scheme; also, of the annual cost of precipitating the sewage. No estimates of the cost of preparing the Saugus marshes to filter the sewage, nor of the annual cost of operating the different schemes, were furnished, except as above stated. To complete the estimates, these additions were made by us. The estimates of the cost of preparing the marshes to filter the sewage were made in advance of the experiments of your Board to determine their availability for this purpose, and before any special plans of this territory had been made. It was found, from an inspection of existing plans and from the report of the Massachusetts Drainage Commission, that there were 1,000 acres of available land in this vicinity which could be reached by the sewage; and it was assumed that the whole of this land would be required for the present population (150,000) of the district to be sewered. As no designs for preparing the filtering area had been made, our estimates of the cost of

* The former of these districts includes the whole of Charlestown, Cambridge and Somerville; the latter includes none of Charlestown, and but one-ninth of Cambridge and one-fifth of Somerville.

this work were based upon some rough sketches made by us in accordance with the common practice of providing mains and carriers to distribute the sewage over the surface and underdrains at a depth of six feet to remove the effluent. The cost of dikes to keep the tide out was also included.

The annual cost of operating the works was estimated upon a liberal basis, and included an allowance for renewals and repairs of all perishable parts, and for the general administration of the works.

The estimates of the annual expenses for the different schemes, with present and prospective populations, are as follows: —

For the North Metropolitan Sewerage System, as recommended by the Board.

Outlet at Deer Island Beacon, population 290,000, . .	$84,700 00
Outlet at Deer Island Beacon, population 513,000, . .	116,200 00

For the Mystic Valley District.

Outlet at Deer Island Beacon, population 150,000, . .	$55,760 00
Outlet at Deer Island Beacon, population 300,000, . .	72,020 00
Filtration at Saugus marshes, population 150,000, . .	66,700 00
Precipitation scheme, population 150,000, ...	132,800 00
Precipitation scheme, population 300,000, ...	222,300 00

The estimates submitted to us were reviewed in much detail, the estimated cost of each of the different items being checked either by comparison with other work or by re-estimating. The result was an approval of the estimates.

Unusual care has been taken in making the estimates of cost, particularly of the scheme recommended. The different special features needed for the proper operation of a sewerage system of this magnitude have been included, and the cost of the works has been estimated on a liberal basis throughout. I am therefore of the opinion that the estimated cost of the North Metropolitan Sewerage System is sufficiently high to cover all ordinary contingencies, and that the works can, with proper management, be thoroughly built for the amount stated, unless there is some large increase in the cost of labor and materials.

Respectfully submitted,

F. P. STEARNS,
Chief Engineer.

Office State Board of Health, Dec. 24, 1888.

REPORT UPON DISPOSAL BY CHEMICAL PRECIPITATION.

By Charles H. Swan, C. E.

Hiram F. Mills, C. E., *Chairman Water Supply and Sewerage Committee of the Massachusetts State Board of Health.*

Sir: — The chemical precipitation of sewage consists in adding certain chemicals to the sewage, whose action is to promote the deposition of the solid and of a portion of the dissolved impurities. They also act as deodorizers. The mixture of sewage and chemicals flows into tanks, where it is allowed to come to comparative or absolute rest. The impurities removed by the process settle to the bottom of the tanks, leaving a clarified liquid, which is drawn off after the chemical action has taken place.

The precipitate is periodically removed from the tanks. In its original condition it contains a large amount of water and is too fluid to be transported as a solid. If the locality admits of ready transportation to the sea by water, it may be removed in the liquid state and be deposited in deep water. Otherwise, the most approved method is to extract the liquids from the precipitate, or sludge, by pressure, leaving the solids in a form which can be readily handled. When in the solid form the precipitate has some value as a fertilizer, dependent upon the nature of the sewage and the kind of chemicals used. Its sale, however, is effected with difficulty, and would be uncertain and unreliable. Usually the sludge has to be got rid of by the cheapest method that will effectually prevent it from causing a nuisance, the method varying in different places.

The clarified liquids derived from precipitation processes, as at present conducted, contain a considerable amount of the dissolved impurities of the sewage, and require further purification. This may be accomplished by discharging them into a stream of uncontaminated water, having a good current and a volume sufficient to

render the resultant mixture very dilute. They may also be purified by application to land, as in some forms of sewage irrigation.

The Mystic and Malden rivers are very small streams in dry seasons, and they frequently remain in this condition for long periods. Tidal action, also, is very vigorous in them, and its effect would be to retard seriously the progress of impurities towards the sea. The discharge of clarified sewage into the upper portions of these rivers cannot, therefore, be recommended. The sewage should be conveyed to the lower portion of the valley, and should be discharged, after treatment, into a current of sufficient strength to convey it to the waters of the harbor within a limited time.

The tidal currents of Boston harbor follow the general line of the main ship channel. The shores of the harbor recede from this channel, and it can be reached at a reasonable expense only from a few points, as at Deer Island, at East Boston, and in the Mystic estuary.

Deer Island is favorably situated for the discharge of sewage into the sea without treatment, and precipitation here appears to the greatest disadvantage, as compared with that method of disposal.

The northerly shore of Boston harbor, between Deer Island and East Boston, is very distant from strong tidal currents, and the cost of a permanent structure of sufficient size to convey the effluent from the shore to these currents, and of sufficient strength to withstand the action of storms, would be so great that any project for precipitation works on the northerly shore of the harbor would be too expensive to compare favorably with the cost of a project for discharging the sewage untreated into the sea at a more distant point.

East Boston, although near the tidal currents, is already thickly populated, and the establishment of precipitation works there, covering a large area, would not fail to arouse great opposition. Moreover, the preparation of a suitable site at East Boston would be very costly.

There remain for consideration the localities bordering upon the estuary of the Mystic River. The one most favorably situated, as regards topography and present occupancy, is in Everett, between Malden bridge and Island End River. It consists of a narrow and somewhat irregularly shaped strip of upland, together with some marsh. The upland is mostly a hill, but it runs down to a flat, low-lying strip, near the mouth of Island End River, conveniently situated for a point of discharge.

I have made a careful study of the tidal action in Mystic River in relation to this locality. If the discharge from the precipitation

works were continuous throughout the tide, the effluent would be carried by the flood current of mean tides as far as the upper end of the estuary of the Mystic, and correspondingly up Malden River. During high courses of tides it would be carried considerably farther up these rivers. These latter tides overflow the marshes, and recur about twice a month, their height and duration varying according to the season of the year and other circumstances.

The effluent, being of lighter specific gravity, would require time to become perfectly diluted by the salt water. During the flood tide first following its discharge the mixture would be imperfect. Upon the recession of the tide, portions of the impurities would doubtless be left entangled among the grasses and spread upon the flats laid bare at low water. This, repeated in varying degrees at every tide, might prevent the passage of an appreciable portion of the impurities to the sea, and might lead to unpleasant results in warm weather. To obviate these objectionable features the effluent should be retained in a reservoir, and the discharge should be limited to the early hours of the ebb tide.

The effect of limiting the discharge to the period between high water and half ebb of each tide, or about three hours, would be substantially as follows. At the end of the ebb the quantity of effluent just discharged would have been carried down to the Narrows between Boston and East Boston, and would occupy a position extending from Fort Point Channel to the junction of the Charles and Mystic rivers. During the succeeding flood the effluent would be carried back into the Mystic, Charles and Chelse arivers, returning in the Mystic River about to the point of discharge, and extending from there to a point below the junction of the Mystic and Chelsea rivers. In Charles River it would probably pass above Craigie's bridge. By this time this effluent would be considerably diluted. On the second ebb tide it would pass farther into the harbor, and would approximately occupy a position from Governor's Island to Fort Point Channel. On the second flood such particles as might be influenced by the currents to return again through the Narrows might occupy a position from the dry dock to Chelsea River, or part might return up the Charles River to the railroad bridges. On the third ebb the effluent would be carried down the harbor to the vicinity of Governor's and Spectacle islands. It does not seem likely that many particles would be constrained to return from these localities to the river from whence they came.

In considering the above descriptions, it should be remembered that a given body of effluent would soon lose its identity by dilution

and mixing, and that its various particles would probably follow different lines, some of them perhaps deviating greatly from the average paths above described. The effect of winds and storms should also be considered. It should also be remembered that at each succeeding ebb a new volume of effluent would be discharged, and that the positions above described as being occupied successively by a given body of effluent would in reality be occupied simultaneously by successive bodies of effluent.

It follows, consequently, that the effluent in various stages of dilution would be constantly present in the lower portions of the Mystic, Charles and Chelsea rivers. It has been asked whether any bad effects would be likely to follow from these conditions, the water into which the effluent would be discharged being *salt*. The discharge of an effluent into salt water is extremely unusual, and I have been unable to obtain any conclusive information upon this point. I would therefore recommend that this question be tested by actual trial on a sufficiently large scale, should it appear likely that the precipitation method would be adopted.

Accompanying this report is a plan of the site under consideration, showing in outline a sketch of proposed precipitation works.

The sewage flows by gravity to the pumping station, where it is raised the necessary height to flow into the precipitation tanks on the hill. On its way it passes the mixing house, where it receives the chemicals that produce the precipitation. These are mixed by machinery with proper quantities of water, and the resulting liquid flows into and is incorporated with the sewage. The mixture then enters the tanks. These outlines are for the intermittent process of precipitation, by which the sewage, after being treated with chemicals, is allowed perfect rest. After a sufficient period of rest the clarified liquids are drawn off and permitted to flow away. In the present instance they would flow into the reservoir, and would be discharged into the river at the proper stage of the tide.

The sludge collected in the bottom of the tanks would be discharged through suitable channels to the river side, where it would be received into scows, towed down the harbor, and deposited in deep water in the bay. If the process of pressing the sludge were adopted, the mixing house would be enlarged to receive the pressing plant, and the sludge would be reduced to the solid form and carried in small wagons to the scows. In the solid form it would occupy a much smaller bulk, and fewer scows would be needed.

The works outlined are proportioned to receive the sewage from Woburn, Stoneham, Winchester, Arlington, Belmont, one-fifth of Somerville, one-ninth of Cambridge, Medford, Melrose, Malden, Everett, Chelsea and East Boston. The towns of Winthrop and

Revere are not included. The present population of these towns is estimated at 150,000. The entire works outlined would provide for a population of 300,000. The ordinary sewage is estimated at 16,400,000 gallons per day for a population of 150,000, and 32,800,000 gallons for a population of 300,000. Additional pumping capacity has been provided to handle storm water.

Very many kinds and combinations of chemicals have been used for the treatment of sewage. At the present time the methods most extensively used are the lime process and the process based upon the use of sulphate of alumina and lime, with or without the addition of a small amount of protosulphate of iron, as circumstances may indicate.

With regard to the lime process, it may be said that the cost of the material is cheaper, but that it produces a larger quantity of sludge. Opinions and statistics differ greatly as to the relative amounts of sludge obtained by these two processes. All agree, however, in showing that the lime process gives the larger quantity. The extra cost of handling this additional amount of sludge is considerable; and from the best comparisons that I have been able to make, I believe that this extra cost will very nearly if not entirely offset the saving in the cost of chemicals when the expense of pressing the sludge is included. If the sludge be disposed of in the liquid state, the lime process may be a little cheaper. Aside from questions of cost, the lime process is said to produce an effluent that will become offensive more quickly than that obtained by the alumina process. As the effluent in this case would be discharged in the midst of a populous district, a high degree of purity is required. I have therefore used the sulphate of alumina process in making the estimates.

The precise amount and proportions of the chemicals would be determined by experiment after the works were started. For the purposes of this estimate, I have used the proportions adopted in England, where this process is in use. The cost is based upon current prices of the chemicals in Boston.

Four estimates are given. None of them include the cost of the system of sewers necessary to convey the sewage to this site. The cost of the sewerage system should be added before comparisons are made with other projects. The estimates are for 150,000 and for 300,000 population. In the estimate for 150,000 many of the items are the same as for 300,000 population, looking forward to the immediate growth of the works. The design for the reservoir is intended to be the same as the reservoir of the project for discharging the sewage untreated into the sea; and I have inserted in the estimate what I understand to be the estimated

cost of that reservoir. This will facilitate comparisons with that project. The first pair of estimates are for the disposal of the sludge in a liquid state. The second pair include the cost of pressing the sludge. They show that the pressing process is the most expensive at this locality. I believe that the disposal of the sludge in the liquid state would give satisfactory results in this case. The works could be modified so as to include pressing if the other method should not prove satisfactory. The works can and should be operated without causing a nuisance. To that end they should be kept under careful management and in a high state of efficiency.

Conclusions.

1. That clarified sewage ought not to be discharged into the upper portions of the Mystic and Malden rivers, but that it should be discharged into strong tidal currents near the harbor, so that it may be dispersed in large bodies of water in a limited time.

2. That a site on the estuary of the Mystic River appears to be the only one that will compare favorably, as regards cost, with other methods of disposal.

3. That the effluent should be retained in a reservoir, and be discharged only between the times of high water and half ebb.

4. That the greater portion of the effluent discharged at a given tide would be carried to the harbor during the third ebb, and would then be finally dispersed.

5. That the works can be operated without causing a nuisance.

6. That, during the passage of the effluent from the works to the harbor, it would be continually present in the lower portions of the Mystic, Charles and Chelsea rivers, in various degrees of dilution, and that experiment is needed to ascertain whether this would be a source of offence.

(A.) *Estimate of cost of works for a population of 150,000; the precipitate being disposed of in the liquid state. (Not including the cost of the system of sewers.)*

Land: —	
$44\frac{84}{100}$ acres upland, at $2,178,	$97,662
$44\frac{44}{100}$ acres marsh, at $100,	4,444
Buildings,	5,000
Precipitation tanks, sludge and effluent channels, etc.,	182,761
Mixing house,	22,858
Machinery, mixers, etc.,	24,500
Store house,	17,639
Earthwork and grading,	29,100
Wharf and trestles,	15,000

Reservoir,		$220,000
Discharge channel and pier head,		52,000
Two tug-boats,	$30,000	
Six scows,	15,000	
		45,000
Manager's house,		5,000
		$720,964
Pumping station: —		
Filth hoist and machinery, pump well and foundations, engine house, boiler house, chimney, and coal sheds,		125,000
Engines and boilers: —		
Two engines (25,000,000 gallons each),	$100,000	
Two boilers and settings,	20,000	
		120,000
Force mains and valves,		13,000
		$978,964
Contingencies and engineering, ten per cent.,		97,896
Total cost of works,		$1,076,860

Yearly Maintenance.

Precipitation, at forty cents per head,	$60,000
Sludge removal,	14,052
Pumping,	13,300
Depreciation, say	10,769
Superintendence,	6,000
	$104,121

(B.) *Estimate of cost of works for a population of $300,000; the precipitate being disposed of in the liquid state. (Not including the cost of the system of sewers.)*

Land: —		
$44\frac{84}{100}$ acres upland, at $2,178,		$97,662
$44\frac{44}{100}$ acres marsh, at $100,		4,444
Buildings,		5,000
Precipitation tanks, sludge and effluent channels, etc.,		357,863
Mixing house,		22,858
Machinery, mixers, etc.,		45,000
Store house,		17,639
Earthwork and grading,		35,132
Wharf and trestles,		15,000
Reservoir,		350,000
Discharge channel and pier head,		52,000
Two tug-boats,	$30,000	
Twelve scows,	27,000	
		57,000

Manager's house,		$5,000
Pumping station,		125,000
Engines and boilers: —		
Three engines (25,000,000 gallons each),	$150,000	
Three boilers and settings,	30,000	
		180,000
Force mains and valves,		19,500
		$1,389,098
Contingencies and engineering, ten per cent.,		138,910
Total cost of works,		$1,528,008

Yearly Maintenance.

Precipitation, at thirty-eight cents per head,	$114,000
Sludge removal,	28,105
Pumping,	29,000
Depreciation, say	15,280
Superintendence,	6,000
	$192,385

(C.) *Estimate of cost of works for a population of 150,000; the precipitate being pressed into solid form. (Not including the cost of the system of sewers.)*

Aggregate cost of items which remain the same as in estimate A,		$703,845
Precipitation tanks, sludge and effluent channels, etc.,		182,154
Mixing house,		27,800
Machinery, mixers, etc.,		55,500
Two tug-boats,	$30,000	
Three scows,	7,500	
		37,500
		$1,006,799
Contingencies and engineering, ten per cent.,		100,680
Total cost of works,		$1,107,479

Yearly Maintenance.

Precipitation, at forty-nine cents per head,	$73,500
Sludge removal,	8,200
Pumping,	13,300
Depreciation, say	11,075
Superintendence,	6,000
Total,	$112,075

(D.) *Estimate of cost of works for a population of 300,000, the precipitate being pressed into solid form. (Not including the cost of the system of sewers)*

Aggregate cost of items which remain the same as in estimate B,		$906,377
Precipitation tanks, sludge and effluent channels, etc.,		365.174
Mixing house,		27,800
Machinery, mixers, etc,		104,000
Two tug-boats,	$30,000	
Three scows,	7,500	
		37,500
		$1,440,851
Contingencies and engineering, ten per cent.,		144,085
Total cost of works,		$1,584,936

Yearly Maintenance.

Precipitation, at forty-seven cents per head,	$141,000
Sludge removal,	9,700
Pumping,	29,000
Depreciation, say	15,849
Superintendence,	6,000
	$201,549

Respectfully submitted,

CHARLES H. SWAN.

Boston, March 5, 1888.

REPORT ON ABSORPTION OF WATER UPON SAUGUS MARSHES.

By Fred. Brooks, Civil Engineer.

Boston, Mass., Nov. 15, 1888.

Hiram F. Mills, *Chairman of Committee on Drainage, Massachusetts State Board of Health.*

Dear Sir: — On Aug. 8, 1888, I was instructed to assume the charge of the examination which was already in progress for the purpose of determining what would be the capacity of the marshes near Pines River to absorb water or sewage, provided the rise and fall of the tide were prevented by excluding the sea and keeping the ground water at about half-tide level.

Salt water pumped up from the marsh was applied so as to stand constantly upon the surface, as the first condition (and that principally studied). The second condition was with water applied intermittently, because sewage would be applied intermittently, if the marshes should be used for its disposal.

A general plan of the marshes has been prepared (see copy accompanying), upon which the positions of the places selected for experiment are shown as Stations 1, 2, 3, 4 and 6; and smaller drawings have been made showing the plan of each station.

Farther on in this report are tabulated results showing the rate per twenty-four hours at which water subsides at each station. In explaining how these results were obtained it is thought simplest to describe Station 6 first.

At Station 6, about the middle of July, a rectangle 22 feet by 12 was inclosed by a low embankment, less than a foot in height, which was built upon the surface of the ground without breaking the turf; exterior to this, with sides parallel to it and four feet distant, another similar embankment was built, which was therefore 30 feet by 20; and a third likewise surrounding the second was 38 feet by 28.

Water was then pumped as required upon the inclosed surface; and its subsidence was observed every two hours, from 7 A.M. to 5 P.M., by measuring with a simple form of hook-gauge the distance down to the surface of the water from a horizontal strip of wood fixed above it. The measurements were made at three places; at the central area, here designated as A, and in the narrow spaces between the parallel embankments, B between the inner embankment and the intermediate, and C between intermediate and outer.

The areas (B and C) exterior to the central area (A) were kept wet in order to insure that the experiments upon the central area should fairly imitate such conditions as would exist if a large part of the marsh had sewage upon it, and should not allow the water upon the central area to percolate sidewise into soil which was dry upon the surface, and so give incorrectly too large a result. The differences between them in rate of subsidence indicate that from C, which has the largest rate, percolation does take place not only directly downwards, but also sidewise into a comparatively dry soil, while from A the water must be supposed to be taken care of by the earth directly beneath it, the surrounding soil being kept saturated, or nearly saturated, by the water from B and C; B shows a rate of subsidence between that of A and C, as might naturally be expected from its position. This relation was maintained regularly, and was very manifest July 29 to August 5, August 29 to September 3, September 13 to 20, September 26 to 28.

The amount of subsidence, however, varies considerably. The observations at No. 6 began about the middle of July, and during a large part of the first month the high tide daily overflowed the marsh and embankments so as to prevent continuous observation. From July 26 to August 5, however, a continuous record was secured. To prevent subsequent interruptions a high dike was built, August 18, inclosing the experimental areas of Station 6, after which date water was generally kept off the space between the outer rectangular embankment and this dike. Within the inclosing dike were four pits, which enabled it to be seen whether water was or was not present in the subsoil. Two, designated "W" and "E," fifty feet apart, were only six feet distant from the outer rectangular embankment on the west and east sides respectively. They were about a foot and a half square and about five feet deep, extending into a stratum of sand very pervious to water. In these the water stood nearly at the same level as in the soil; for after pumping out one of them, it refilled, the water rising in it 2.3 feet in twenty-three minutes. During the high range of

tides, even after the dike was completed, the water rose in these pits to the surface of the ground and sometimes flowed out upon it. The large pits designated as "near Station 1" and "near Station 2" were fifty or sixty feet from Station 6, and on account of their larger area and storage capacity were less accurate gauges of the water in the soil. During the low range of tides there were periods when the ground water was seen to be down and to stay down several feet in these pits, and also in the "main ditch" which ran along the south-west side of the inclosure, and connected with the tidal channel only by a tide-valve. Except during the low range of tides this ditch was completely filled at high water by the overflowing of the marsh. Generally speaking, the lower the water surface stood in these pits, the more rapid was the subsidence in the inclosed areas, as the subjoined table shows: —

DATE.	Distance down from the Surface of the Ground to the Surface of the Water in the Pits. Feet.	Rate of Subsidence per 24 hours at Area A. Inches.
Aug. 30 – Sept. 4, ...	3.5	From 2.4 to 2.7
Aug. 1 – 2, ...	2.0	1.9
July 28 – 9, ...	1.5	1.6

The diagram of daily summaries for August 23 to 30 is in substantial conformity with these figures; as were also, in spite of the treatment having become intermittent, some of the later observations, such as those of September 26 to 30.

At Stations 1, 2, 3 and 4 the arrangement finally adopted was similar to that at Station 6, above described, with the exceptions that the embankments were circular instead of rectangular, that at and around those areas considerable disturbance of the soil had taken place in the earlier stages of the work, and that at them (as never at Station 6) pumping of water out of drain-boxes about five feet beneath the ground was resorted to at high water during all the latter portion of the observations, with the intention of keeping the level of the ground water down where it would be if the marshes were drained and the sea excluded by dikes. Stations 1, 2, 3 and 4 each had two areas to be experimented upon, on one of which the grass was left growing, while from the other the turf was stripped off and replaced by peaty material of the marsh to restore the level of the surface. At Stations 1, 2 and 3 only two

embankments were concentric; their outside areas (C) were of irregular form extending to the surrounding high dike, grass C and stripped C being separate from each other with the pump-well between them.

Observations were taken every two hours during the daytime at the several stations with their subdivisions, and also at numerous gauges in the pits, ditches and creeks, so that over three hundred readings were taken daily during the busiest part of the work.

In order to give a comprehensive view of the experiments, there have been plotted on a single sheet the more important determinations of the rate of subsidence in inches per twenty-four hours; from this diagram the average rates observed can be estimated by inspection, but some corrections are required.

In the first place, allowance must be made for evaporation. The observed subsidence is due both to percolation and evaporation. The evaporation required to be known for this investigation is, therefore, the evaporation actually taking place from small areas about 14 feet in diameter surrounded by embankments; this is to be applied as a correction by deducting it from the total subsidence to get the amount of percolation into the ground. The required rate of evaporation was fairly determined by observations made upon shallow pans surrounded by low rims, and exposed to the sun and wind on the marsh like the experimental areas.

Another correction is required on account of the thickness of the embankments; the water is poured upon the surface between the embankments, but when it gets beneath the ground it can spread into the space under the embankment, so that for a fair measurement the observed rate of subsidence must be diminished in a ratio estimated as $3.14 \times (7\frac{1}{2})^2 : 3.14 \times (6\frac{1}{2})^2$, or about as 52 to 42. At Station 1 grass, on account of its smaller area and proportionally longer embankment, twenty-five per cent. is taken as the deduction on this account. At the other stations twenty per cent. is considered sufficient.

An addition should be made to the observed rate of subsidence for that portion which takes place and is not measured during the time of pumping water onto the areas. If this took a quarter of an hour in every twenty-four, it would be one per cent.; it, of course, varies with the rapidity (and resulting quantity) of water disposed of, and in the outside areas (C), some of which are large, it would be more than one per cent., while in the intermediate areas (B) it would probably be less than one per cent., which is estimated as about the amount of this correction for the central areas (A).

From the lines plotted on the general diagram of the results of

observations under varying conditions from August 8 to September 4, the following estimate is made of the general rate of subsidence, after making the various corrections above mentioned: —

Area.	Rate in inches per 24 hours.
No. 1, grass,	2.7
No 1, stripped,	1.1
No. 2, grass,	1.4
No. 2, stripped,	1.2
No. 3, grass,	0.8
No. 3, stripped,	0.85
No. 4, grass,	0.15
No. 4, stripped,	0.11
No. 6,	1.66

That the rates at the several areas from time to time increase and diminish nearly alike, as the diagram shows, suggests that the cause of the variation is something that affects all together, like the weather or the range of the tide. The facts above stated with regard to the pits near Station 6 show that for moderate distances within the dikes there is pretty free percolation of water, at least in the sandy sub-soil. The central areas experimented upon were as near to the exterior marsh as they were to the drain-box. Hence, when high water every day overflowed the marsh exterior to the dikes, it is improbable that the water-table at the central areas was kept down, as desired, to as low a level as in the pump-wells, or that the results of the observations gave a trustworthy determination of what would take place were the whole marsh drained by excluding the tide, even though some imperfections be allowed for (as leakage through the dikes and accumulation of water from the adjacent uplands), and in spite of the fact that water in the ground between proposed lines of drainage would stand higher than in the drains themselves. At the other stations, as at No. 6, by far the most satisfactory information was obtained during periods when the tides ran low, and the marsh generally was not overflowed; such periods were from May 15–20 (slight rains daily), June 2–7, July 1–6, July 29–August 5 (about one-half inch rain August 1), August 30–September 4, September 25, and September 27–October 1.

From the diagrams of the observations at dry periods, and for Stations 1, 2 and 6 for the period from August 29 to September 4, when the rates were observed to be regular, the following estimate is made as a fair determination of the rate at which water can be disposed of at the several places under a continuous treatment.

For the selected period, August 29 to September 3, the evapora-

tion as observed is deducted day by day as shown on the diagram. It averages about 0.15 inch per day.

Area.	Rate in inches per 24 hours.
No. 1, grass,	3.7
No. 1, stripped,	1.2
No. 2, grass,	1.45
No. 2, stripped,	1.25
No. 3, grass,	0.75
No. 3, stripped,	0.70
No. 4, grass,	0.08
No. 4, stripped,	0.07
No. 6,	1.95

Intermittent Treatment.

The question has to be determined whether the water goes down faster, and if so, how much faster, when there is air in the void spaces of the soil than when they are filled up with water. For this purpose the exterior areas (B and C) being kept wet, the central areas (A) are allowed to run dry, and then to rest long enough for the water to settle away to some depth below the surface of the ground; the rule adopted was that the intermission with the surface dry should be as long as the time that had been required for the disappearance of the quantity of water put at intervals upon the area, and was approximately adhered to; though this was not always exactly feasible, as the disappearance sometimes took place unobserved in the night, and the surface of the stripped areas shrank away when left dry so as to make the measurement of the depth of water poured upon them somewhat uncertain. The best way to compare the subsidence when water is kept standing upon the ground and the subsidence when the ground has been dried, would be to take the times respectively required under the two conditions for the water to go down between the same readings on the gauges; but as the observations actually taken extend to different gauge-readings, it affords a larger basis of comparison not to limit the comparison strictly to this condition.

Though the result is that on the whole the "aerated" shows larger figures than the "saturated," no uniform ratio of excess is maintained, and it is probable that the observed differences are partly due to difference in the stages of the tide.

The increased rate with aeration is much less than double the rate with saturation; in the case of aeration subsidence goes on for half the time, while in the case of saturation it goes on during the whole time; hence, the intermittent treatment permits the absorption of considerably less water than the continuous.

The following table contains for comparison results with soil saturated on the right-hand side, and with soil aerated on the left; the figures are in inches of subsidence per twenty-four hours: —

Comparison of Rates of Subsidence according as the Soil to which Water is applied was previously saturated or previously aerated.

Station 1 — Grass.

Aerated.	Saturated.
Sunday, Sept. 30 — Monday, Oct. 1. (G/o) 3.59 and 3.65 (G/A).	Wednesday, Sept. 26 — Friday, Sept. 28. (G/o) 3.66, 4.29 and (G/A) 3.77, 3.95.

Station 1 — Stripped.

Saturday, Sept. 29 — Sunday, Sept. 30. 1.25	Wednesday, Sept. 26—Thursday, Sept. 27. 1.01

Station 2 — Grass.

Saturday, Sept 29 — Sunday, Sept. 30. 1.65	Wednesday, Sept. 26— Thursday, Sept. 27. 1.14

Station 2 — Stripped.

Saturday, Sept. 29 — Sunday, Sept. 30. 0.99	Wednesday, Sept. 26—Thursday, Sept. 27. 0.96

Station 3 — Grass.

1.374	0.973

Station 3 — Stripped.

1.20	1.26

No. 6.

Saturday, Sept. 29 — Sunday, Sept. 30. 2.40	Wednesday, Sept. 26—Thursday, Sept. 27. 1.62

The comparison of the different rates of subsidence at the central areas (A) of the several stations requires, for any useful

results, to be accompanied by a statement of the material at the stations.

The character of the material at each central area where observations were made was determined by digging into it after they were completed; samples taken at depths of 1, 2, 3 and 4 feet beneath the surface were put into bottles, marked, and sent to the officers of the State Board of Health. At Stations 3 and 4 peaty material was found all the way down, its bottom being reached at 3 grass, 5.1 feet down; at 3 stripped, 5.7 feet. At Stations 1, 2 and 6 sand was found at the following depths below the surface: —

No. 2, grass,	1.5 feet
No. 2, stripped,	1.6 "
No. 6,	1.7 "
No. 1, grass,	1.75 "
No. 1, stripped,	2.4 "

The material other than sand was of a similar peaty character in all, except that at No. 2 stripped, at a depth of two feet, there was some yellow clayey material; an additional sample of this was taken from a depth of about 1.6 feet.

At Station 1 the central grass area (G/A) has sand nearer the surface than the exterior area C, or than is found outside the dike at the marsh adjacent on the north-east.

On comparison of the grass areas with the stripped areas at each station, it is generally found that the subsidence at the grass areas was greater, which is explicable on the theory that the water passes down through or alongside of the roots of the grass; that it must readily do so cannot be doubted, for the roots extend down through the peaty material to great depths, and many of the dead ones are pipes of visible calibre. In the cases of Stations 1 and 2 the slower rates at the stripped areas may be attributed not merely to the fact of the stripping, but also to the considerably greater depth of the peaty material at No. 1 S, and to the admixture of a little clay with the sand at No. 2 S.

The observations compared should be simultaneous, for at the same station different results were found at different times, presumably on account of the different conditions of the tide and of the atmosphere.

The simultaneous rates of absorption at the several areas maintained a fair degree of regularity comparatively to one another; and corresponded approximately with the depths of peaty soil at those areas respectively; for the smallest result was obtained at Station 4, a small one at Station 3, larger at Station 1 stripped,

and larger still at Stations 2 and 6 and Station 1 grass; but the rates at the last named do not vary precisely according to their depths of peaty material. Station 2 grass, Station 2 stripped and Station 6, may be classed together as having nearly the same depth of peaty material and nearly the same rate of subsidence; but Station 1 grass, with no less depth, had double the rate, which the writer is at a loss to explain. It is suggested that possibly the grass growing at Station 1 may differ from that at Station 6, as it seemed on digging into Station 1 grass, A, as if there was an uncommon amount of roots.

Not all the land where the sand stratum was found nearer the surface than at Stations 1, 2 and 6 can be depended upon to give a higher rate of subsidence.

On the south side of Pines River a very hard substratum was sometimes found, consisting chiefly of very fine and compact sand, and along the edge of the upland there was some admixture of clay. North of the Trotting Park fresh water sometimes stood on the surface half a foot in depth, so as to preclude the idea that there is very free percolation. There are places noted on the plan as "sand-bars," generally elevated as compared with the adjoining marsh, where sand is found at very slight depth and often shows on the surface, though there is muck mixed with it and grass growing at all places, with insignificant exceptions. A noticeable elevated tract lies north of Bristow Street, which includes some of the best material for sewage disposal.

Inquiries as to the value of the land show that when it is used for raising marsh hay, that which is most sandy and best adapted for sewage purification is worth the least to the farmer. Some of it has been sold as low as $25 per acre, while that with more peat brings $75. The Saugus assessors value it all at $50; but if it should have to be bought for sewage disposal the price would doubtless be higher, and may be estimated at $100 per acre. The land which is cultivated for vegetables, being higher or protected by dikes, may be estimated at from $250 to $400 per acre, the former probably being as much as it is really worth, and the latter what it could be bought for. The assessed valuation of the land included with the Trotting Park property is $7,400 for 64 acres, the buildings being valued at $6,800. An estimate of the total price of the 598 available acres having less than two feet of peaty material above sand is $83,200, as follows: —

78 acres at $400,	$31,200
520 acres at $100,	52,000
	$83,200

Newhall's Spice Mills on Ballard Street near the Turnpike use tidal power; and above the mill, therefore, the water is not allowed to go below about half-tide level, as appears from the observations made September 24–27, and plotted in connection with the continuous profile for those days. The area which is thus controlled extends along the north-west side of the Turnpike from Ballard Street beyond Bristow Street, the dam marked on the plan being for the purpose of preventing the water from finding an outlet to the southward. Much of the area used by the mill is land that would be of little value for sewage disposal. Instead of paying to the owner enough to provide him with equivalent steam power, dikes might be so built as not to include this land which he flows; but in that case, on account of the higher level of the water outside, the maintenance of the low level within would be more difficult. The Saugus assessors value the mill and water privilege at $9,000.

Very respectfully,

FRED. BROOKS.

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